FINAL REPORT

Rehabilitation Project for Runaway Bay Beach Antigua and Barbuda

Havana, Cuba
August / 2022

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

KOICA
Korea International Cooperation Agency

IMPACT ASSESMENT OF CLIMATE CHANGE ON THE SANDY SHORELINES OF THE CARIBBEAN: ALTERNATIVE FOR ITS CONTROL AND RESILIENCE

REHABILITATION PROJECT FOR RUNAWAY BAY BEACH, ANTIGUA AND BARBUDA

GAMMA
TECNOLOGIA Y MEDIO AMBIENTE

August 2022

AUTHORS

PAVEL MORALES DÍAZ, BSc.

LEONEL IVÁN PEÑA FUENTES, MSc.

ADRIÁN NIÉVARES PÉREZ, BSc.

LINNET BUSUTIL LÓPEZ, MSc.

MIGUEL FELIPE HERNÁNDEZ, Tech.

ACKNOWLEDGEMENTS

The valuable contribution of the Association of Caribbean States, especially its Secretariat and the Disaster Risk Reduction Directorate, was indispensable for the culmination of this Project. Therefore, we would like to express our eternal gratitude to:

- His Excellency Rodolfo Sabonge, Secretary General of the ACS, for his confidence in our institution and his support for the successful development of the project.
- Mrs. Ana Leticia Ramírez Cuevas, Director of the Disaster Risk Reduction Department, for her contribution in the start-up and completion of this project.
- Mr. Colin Peter Jack, Project Manager of Sandy Shorelines Project, for his collaboration and support in coordinating insurance and logistics for the execution of field work.

Our deepest appreciation to those who collaborated with the project from the Fisheries Division of the Ministry of Agriculture, Fisheries and Barbuda Affairs, of the Associated State of Antigua and Barbuda, in their capacity as Focal Point of the project. Their invaluable support contributed to the success in the delivery of the Postgraduate Course and Seminar, as well as in the execution of field and laboratory works. Special thanks to:

- Mr. Mark Archibald.
- Mr. Hilroy Simon.
- Mr. Jerelle Aaron.

And to the Cuban Embassy in Antigua and Barbuda, to its Ambassador Mrs. María Esther Fiffe and Consul Dr. Alejandro Colas, for the support provided.

CONTENTS

I. INTRODUCTION

In January 2021, Contract 2/DECS/2021/01SS was signed between the Association of Caribbean States (ACS) and "Inversiones GAMMA SA", company under the Ministry of Science, Technology and Environment of Cuba, with the objective of preparing three executive beach rehabilitation projects, including the beaches Viento Frío (Colon, Republic of Panama), Runaway Bay (Antigua, Antigua and Barbuda), and Bonasse (Cedros Bay, Republic of Trinidad and Tobago).

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

In correspondence with a Contingency Plan, and as a result of the arrangements carried out by GAMMA, an advance group of six Cuban specialists and engineers travelled to Panama, with measurement equipment, starting the field works in Viento Frío Beach on August 13th, 2021, eighteen days before the agreed date.

The complex world health situation continued during the following months, thus reducing the availability of flights. Therefore, GAMMA's team had to continue working by telecommuting, while coordinating at the same time the beginning of field works for the remaining two case studies.

Finally, on April 17th, 2022, two teams of Cuban specialists simultaneously arrived at Antigua and Barbuda, and Trinidad and Tobago, with the technical equipment necessary to start the field works.

In view of the objective reality at the time, a new readjustment of participants and work schedule was necessary, always maintaining the agreed quality standard.

In the case of Antigua and Barbuda, after a fast coordination on the ground, and with the outstanding support of the Focal Point, field works were carried from April 21st to June 15th.

Field works conceived in the Technical Task, which are part of the contract for the preparation of the executive project for the recovery of Runaway Bay Beach, were completed satisfactorily.

The following are among the main results obtained:

- Reconnaissance of the study area.
- Topographic survey of the beach and the coastal zone.

- Exploration of the seabed surface in search for marine sand deposits with potential to use as a borrow area for a possible artificial sand nourishment project.
- Bathymetric survey of the seabed along the shoreline of the study area and in the proposed borrow area.
- Sampling of sand from the beach and the proposed borrow area.
- Laboratory analysis of sand samples to determine its grain size and composition.

Weekly reports on the actions taken during the period were prepared and sent to the interested parties.

Once the field works were completed, a progress report was delivered describing the main tasks performed and illustrating the advancement of the Rehabilitation Project for Runaway Bay Beach, in Antigua and Barbuda, until then.

After the conclusion of field works, the processing of obtained information continued, including available time series of variables of interest, as well as the preparation and execution of numeric simulations of wave, coastal currents and coastal sediment transport.

The study of the available bibliography and the results obtained from the research carried out have allowed characterizing the study area, identifying evidence and causes of the erosion process, and designing alternatives for the recovery of Runaway Bay Beach.

Likewise, this project report includes proposals for management strategies, with actions to develop at short, medium and long term to preserve the beach conditions, once recovered, in view of the foreseeable impact of extreme weather events and the forecasted climate change-induced increase in mean sea level.

II. PROJECT JUSTIFICATION

The erosion of sandy beaches constitutes a global issue, being particularly harmful for those countries whose economies depend on tourism, in the sun and beach modality, such as the small island states in the Eastern Caribbean Sea.

In the last decades, evidence showing the widespread nature of beach erosion on a global scale has been accumulated, and although local human action constitutes the essential cause of issue in many cases, the evidence of erosion is also present on beaches with null or almost null anthropogenic intervention.

The Intergovernmental Panel on Climate Change (IPCC) had warned that coastal areas would be the first affected in a scenario, in which the processes that gradually lead to global climate change advance and accelerate.

In its VI Report (2022), the IPCC points out that, in the latest 25 years, until 2018, mean sea level increased in 8.1 cm, a value equal to the accumulated estimate for 60 years between 1930 and 1990; the annual increase rate between 1993 and 2018 has been 2.4 times higher than the measured rate between 1901 and 1990, and this, in turn, is higher than the estimated value for any century in at least 3000 years.

It is expected that mean sea level rise will lead to the development of erosion processes in sandy beaches. The presence of evidence of erosion, even in beaches with no human intervention, as well as the widespread character of erosion at global scale, allow to relate both phenomena.

II.1 Beach erosion in small islands of the Eastern Caribbean Sea.

In the report "Diagnosis of Erosion Processes in Caribbean Sandy Beaches" (UNEP, 2003), prepared by Cuban environmental specialists within the framework of the Project "Physical Alteration and Destruction of Habitats" of United Nations Environment Program, a summary is included of studies carried out during the last decade of 20th century by Dr. Gillian Cambers and several local collaborators, on different beaches of small islands in the Eastern Caribbean Sea.

The results of this research revealed that 70% of the studied beaches registered a shoreline retreat that ranged between 0.27 m/year and 1.06 m/year (Table 1).

Table 1: Summary of results obtained by Cambers between 1985 and 1994, in the study of erosion processes in beaches of small island states of the Eastern Caribbean Sea (UNEP, 2003).

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

Erosion resulted from a combination of natural and anthropogenic factors. Among the natural ones, Cambers (1997) points out the tidal waves generated mainly during the northern winter and the passage of hurricanes, as well as sea level rise. Among the most important anthropogenic factors, she identifies mining activity in the coastal areas, facilities very close to the beach, incorrect location of coastal defense structures and destruction of barrier reefs (UNEP, 2003).

II.2 Brief rationale of the Runaway Bay case, in Antigua.

James (2017), in a technical report sponsored by the Fisheries Division of the Ministry of Agriculture, Land, Fisheries and Barbuda Affairs, summarized the results of the monitoring of 19 beaches distributed along all the coast of Antigua, between 1995 and 2015. For the whole period, the balance turned out negative only in 3 cases, among which Runaway Bay was not included (Fig. 1).

However, the report warned that, during the 2009-2015 period, erosion processes had predominated in 13 of the 19 monitored beaches (Fig. 2).

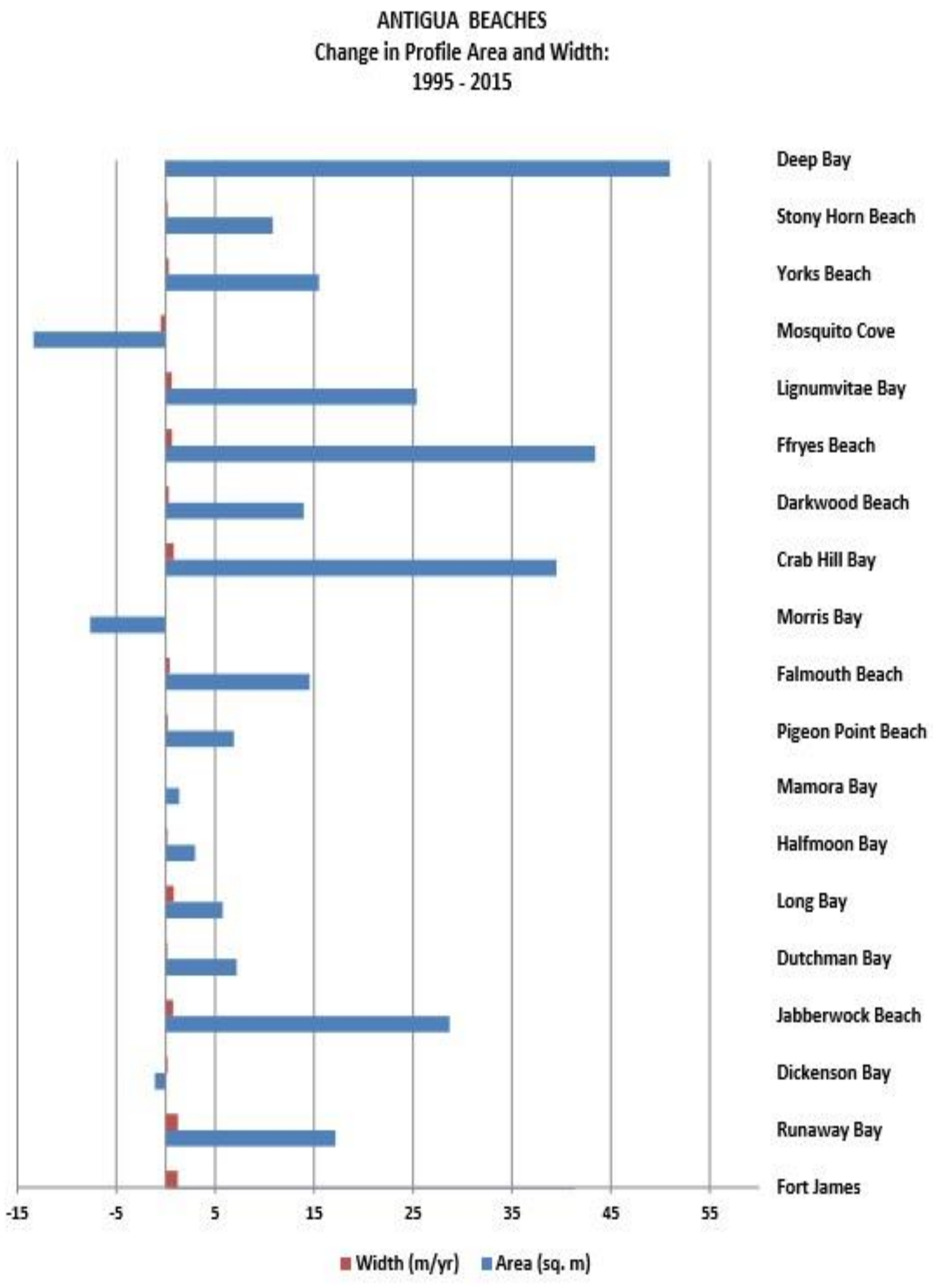


Figure 1: Summary of monitoring results for 19 beaches in Antigua between 1995 and 2015. Variation in Beach Width (m/year) and Beach Area (m^2) (James, 2017).

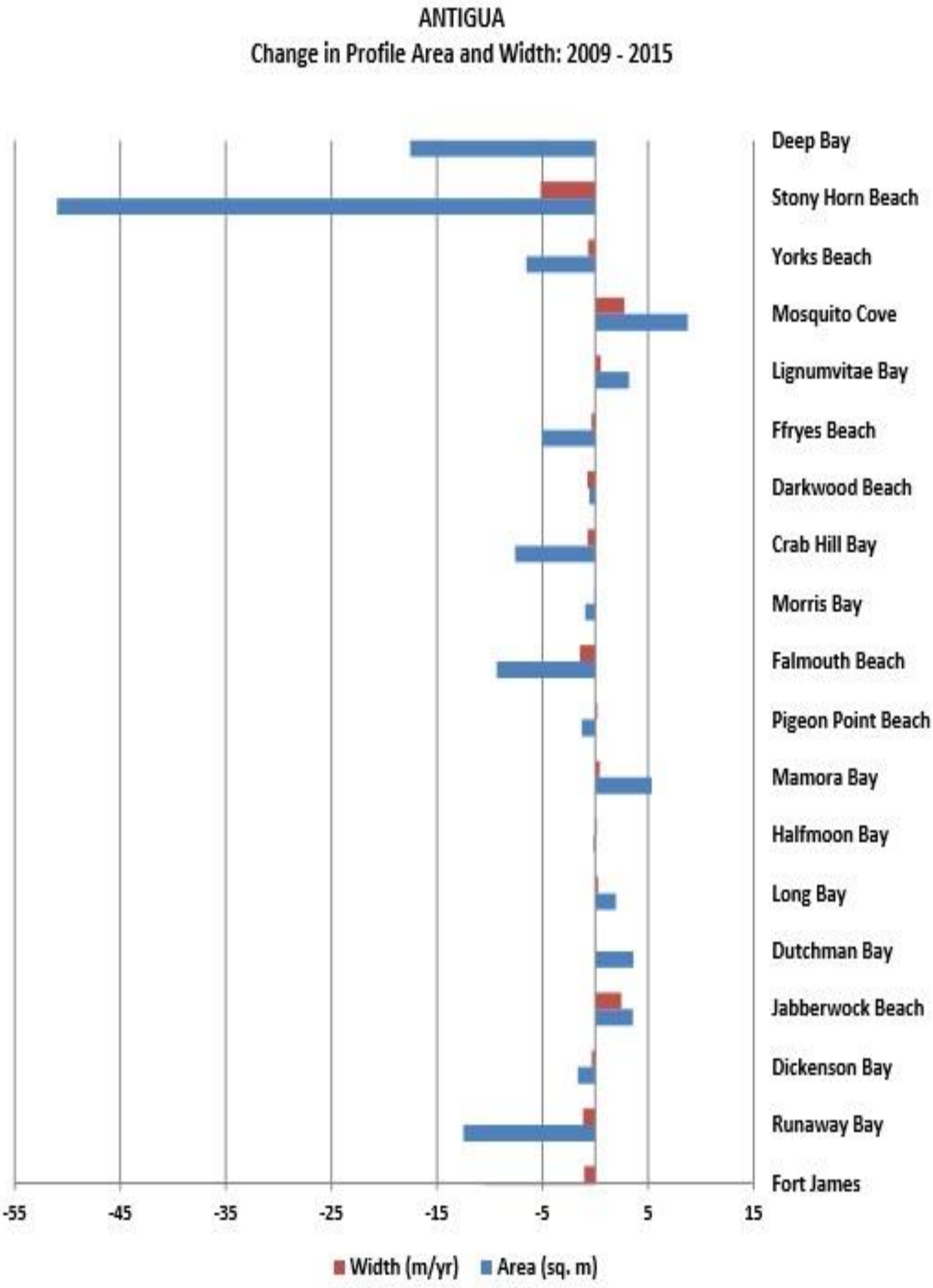


Figure 2: Summary of monitoring results for 19 beaches in Antigua between 2009 and 2015. Variation in Beach Width (m/year) and Beach Area (m^2) (James, 2017).

In this last period, Runaway Bay is included among the beaches that registered a shoreline retreat of 1.134 m per year (James, 2017), based on annual measurements in two profiles whose explicit location was included in the report. Such annual rate classifies as Moderate Erosion, according to Juanes (1996).

According to this information, the erosion process did not seem to be too intense, and in fact, it could just be an erosion period motivated by the coincidence of the passage of certain number of tropical cyclones. However, this was not consistent with the magnitude of the noticeable anthropogenic intervention in the center and north sectors of the beach, characterized by the construction of coastal defense structures financed by the owners of the buildings occupying the dune.

The review of the chronology of satellite images available in Google Earth did not contribute relevant information, since they were barely about ten images taken at irregular intervals. It only allowed determining the construction date of defense structures, built as breakwaters and groynes, located in the center of the beach, executed in different stages between 2010 and 2018.

A more detailed bibliographical review allowed observing some elements previous to the referred monitoring initiated in 1995, so that it was possible to understand the magnitude of the erosion process suffered by Runaway Bay Beach, and some of its possible causes:

- According to Albuquerque and McElroy (1995), and Baldwin (2000), the Marina Bay project was executed between 1986 and 1989. It included dredging the access channel and building the breakwater that currently limits Runaway Bay to the north. Such project has probably contributed to reduce sandy sediments inputs to Runaway Bay from Dickenson Bay.
- Previously, and particularly in the 1980s, certain real estate development with tourist purposes took place in the north sector of Runaway Bay, which was limited due to the abandonment of the project conceived for Marina Bay and McKinnon's Salt Pond, given the technological difficulties for its execution, the serious environmental problems unleashed, and popular demand (Albuquerque and McElroy, 1995; Baldwin, 2000).
- For decades, sand mining was practiced in beach dunes, specifically in the Dry Hill area, for construction purposes, which continued illegally despite being prohibited by law in 1957 (Albuquerque and McElroy, 1995; Baldwin, 2000). This limits the sand reserves of the beach, decreasing its resilience capacity when facing the impact of extreme weather events.

- There are references of the execution of important dredging projects in Green Bay (located south of Runaway Bay and Fort Bay, where Saint Johns Harbor is situated) during the last years of 19th century, as well as in the 1960s and 1980s (Baldwin, 2000). This is an element to consider in the study.
- In September 1995, Antigua and Barbuda were affected by the passage of the powerful Hurricane Luis, category 4 in Saffir–Simpson scale, with great impact on several beaches, according to various reports.
- Specifically, a report financed by UNESCO (2000), with the participation of the Fisheries Division, and other national and international institutions, allowed to notice the effects of this moment of intense erosion in the north sector of Runaway Bay Beach, whose beach has been lost since then and has not been able to recover until the present (Fig. 3 and Frame 1).

The consulted reports, images and information allowed us to suspect the development of an intense erosion process in Runaway Bay Beach, lasting several decades, and with genesis in a combination of natural and anthropogenic causes. Such situation leads to the need to carry out field research, numeric simulations and laboratory analysis conceived in the Technical Task, as a basis to study coastal dynamics in the study area, identify the specific causes of erosion, design a engineering solution, and define strategic lines for beach management in the short, medium and long term, for its recovery and preservation in view of the foreseeable impact of extreme weather events, enhanced by the increase in climate change-induced mean sea level rise in the future.

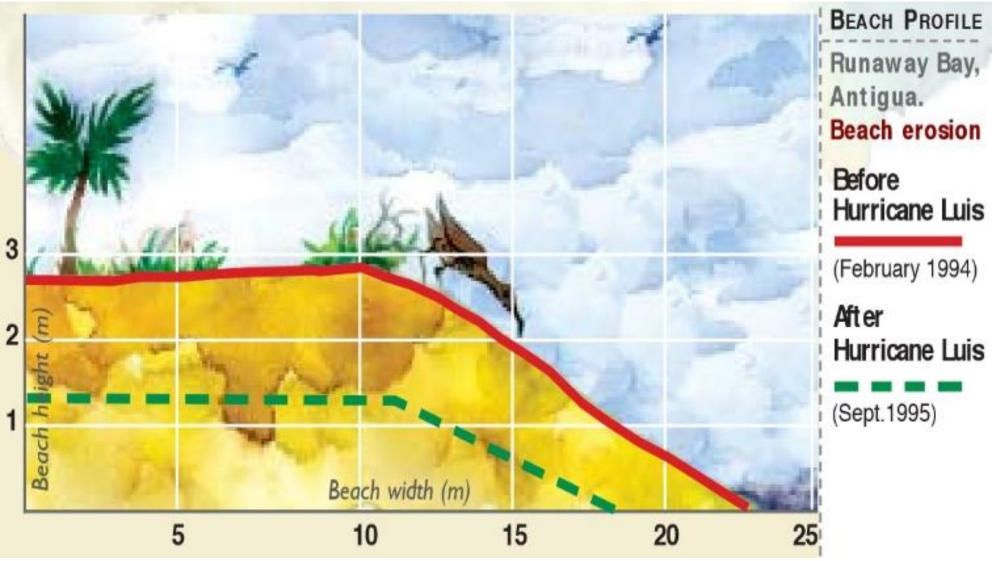


Figure 3: Runaway Bay Beach. Comparison of mean profiles before and after the impact of Hurricane Luis in September 1995 (UNESCO, 2000).

Frame 1: North sector of Runaway Bay Beach in 1994 (top left) and 1996 (top right) before and after the impact of Hurricane Luis in September 1995; same sector in 2022 (bottom).

For all these reasons, and as agreed, the objectives of the research are as follows:

General Objective:

- Design the executive project for the rehabilitation of Runaway Bay Beach, Antigua, Antigua and Barbuda.

Specific Objectives:

- Establish a geodetic basis for topographic, hydrographic and geophysical surveys, and future monitoring of beach geomorphological indicators.
- Carry out cross sections for beach morphological characterization, as well as the position of the shoreline.

- Carry out the bathymetric survey for seabed morphology characterization and for mathematical simulations.
- Characterize the sediments that make up the beach.
- Simulate the hydrodynamic processes on the coastal front of interest with the use of mathematical models for wave propagation, generation of littoral currents, sediment transport and post-storm evolution of the beach profile.
- Establish the scheme of the coastal system functioning, identifying the causes of the erosion process.
- Locate and evaluate possible sand borrow sources for the execution of beach rehabilitation works.
- Identify engineering alternatives for erosion control and shoreline protection.
- Establish the technical and design parameters of the proposed solutions.

II.3 Elements to consider for solution design.

This kind of research is initially aimed at characterizing the state of the beach under study and identifying evidence of the erosion process and its causes.

Establishing the causes of erosion is fundamental for the definition of proposed solutions, since these should include measures explicitly aimed at reversing the situation that favors such causes.

For example, if the beach is eroding due to an increase in the energy of the usual wave regime, or the frequency of storm waves, it may require the construction of dissipative structures to ensure the stability of the sand in the profile: however, this solution by itself, will not be able to return the lost sand to the beach, so it will probably have to be complemented with the application of artificial sand nourishment.

It should also be considered that sandy beaches in good condition are very effective in dissipating wave energy, so that, their recovery through sand nourishment is usually the most suitable solution, and also, when the root cause is a decrease in the contributions of natural sand-producing sources.

In any case, the approach of the proposed solution to be conceived must include 3 fundamental components: morphological, aesthetic and functional; which in general terms lead to the restitution of the morphological elements that make up a typical beach profile, and in particular, the pre-existing one in the study area; the rescue of its natural landscape values; and a double value of use in the functional aspect, obtaining a beach recovered in such a way that it is attractive and capable of sustaining a tourist and recreational use, and at the same time dissipates the energy of the waves and avoids possible penetrations of the sea.

At present, the forecasts of rising average sea level, induced by Climate Change, and its erosive effect on the beaches, among other elements, make it necessary to design a management program in addition to the actions to be carried out in the short and medium term, and the strategic guidelines for the long-term management of the beach.

It should also be understood that practice shows that in general there are no definitive or unique solutions to beach erosion; rather, it is necessary to design management programs that implement different measures and actions that complement each other in order to reverse the scenario that causes erosion and control its effects.

Long-term management must necessarily include monitoring, the effectiveness of the actions implemented, and the morphodynamic evolution of the beach, as a tool for the continuous improvement of the management strategy, and the design of new actions, including periodic maintenance of the works implemented, whether they are rigid structures, beaches recovered by sand nourishment, or reconstituted dunes, etc.

The methodology followed during the research will allow proposing the most suitable solutions according to the state of the beach, so that they are explicitly aimed at responding to the causes that favor its erosion, prioritizing, whenever feasible, the application of a Climate Change Adaptation approach based on the Rehabilitation of Ecosystems, and the Sustainable Management of Natural Resources as a basis for Development.

III. MATERIALS AND METHODS

III.1 Field works.

III.1.1 Reconnaissance of the coastal area.

An exploration was carried out along the entire shoreline of Runaway Bay Beach, and the adjacent Dickenson Bay (to the North), and Fort James (to the South). By sea, the shoreline was explored a little farther north. By land, emphasis was made on the reconnaissance of the whole profile of Runaway Bay Beach, including the vegetation and buildings that occupy the coastal area.

The objective of the preliminary reconnaissance is to identify the main morphological and geological elements that make up the coastal area, and evidence of the characteristics of beach dynamics, beach erosion process and its possible causes.

III.1.2 Topographic Survey.

The point of departure was one of the topographic benchmarks, whose coordinates were provided by the Focal Point. It is located in the ruins of an ancient fort in Rat Island, in Saint Johns Harbor. From there, two pivots were measured, before placing 8 points that constituted the baseline from which the survey points were measured. A high-precision KQGEO geopositioning system (GPS), with real-time kinematic technology (RTK) was used (Frame 2).

Frame 2: Survey of control points from the topographic benchmark in Rat Island, with coordinates provided by the Focal Point, using a high-precision geopositioning system (GPS) with real-time kinematic technology (RTK).

The topographic survey of Runaway Bay Beach was carried out by combining the use of aforementioned GPS-RTK system and a Leica TS-09 Total Station (Photo 1).

Photo 1: A Leica-TS09 Total Station was also used in the beach topographic survey.

III.1.3 Bathymetric Survey.

The objective of this study is to know the features of seabed relief, including Runaway Bay Beach coastal front, and the proposed borrow area.

In addition, knowing the seabed characteristics allows for an adequate numeric simulation of wave transformation processes in shallow waters and, consequently, for simulating the behavior of coastal currents and coastal sediment transport. This information is also useful in determining the navigation areas for the dredger, and defining the position of sand discharge pipelines, in case it is proposed to execute an artificial sand nourishment project as a solution for beach recovery.

The survey was carried out with an SDE-28S Echosounder that operates with a 200-kHz frequency and guarantees a 10-cm precision in depth measurement (Photo 2).

Using PowerNav software, this equipment significantly facilitates navigation and survey data acquisition, as well as its subsequent processing.

Photo 2: SDE-28S Echosounder, installed in the boat used to carry out the bathymetric survey.

For secure recording of positioning during the surveys, a Hemisphere VS 100 GPS Receiver was used (Fig. 4), a device that provides accurate and reliable information at high update speeds, allowing to assign coordinate data to each depth record obtained by the echosounder. For that purpose, it has a high-performance GPS engine and two multipath antennas for GPS signal processing.

Figure 4: Hemisphere VS 100 GPS Receiver.

The equipment was installed in a small boat, with the appropriate characteristics in terms of maneuverability, necessary to maintain the direction of the sounding lines, and a draft that allows to approach the coast (Photo 3).

Photo 3: Bathymetric survey of the submerged slope in front of Runaway Bay Beach and adjacent areas, including the proposed borrow area, using an echosounder installed in a small boat rented from a local supplier.

III.1.4 Reconnaissance, drilling and sampling of the seabed.

Before beginning the field works, several zones were defined along the shoreline, which should be explored in order to select the most suitable to be used as a borrow area, for a possible beach restoration project through the application of artificial sand nourishment.

A work plan was defined for the exploration that included conducting diving stations every 50 m (Frame 3), sampling the seabed, measuring the sand layer thickness by using a 1.65 m-long manual auger, and the description of seabed, checking that there are no obstacles such as rocks, coral reefs, or others.

Frame 3: Exploration, drilling and sampling of the seabed by autonomous diving.

III.2 Field information processing.

Obtaining the primary data of the topographic survey was carried out using Leica Flex Office software, for measurements made with Leica TS-09 Total Station, and FieldGenius 9.0, KQGEO RTK equipment's own software.

Data obtained during the bathymetric survey were corrected and exported using PowerNav, SDE-28S Echosounder's own software. In the absence of official tide tables or instrument records that could be used to correct the depth records obtained during the surveys, we relied on the published forecasts for Saint Johns Harbor, found at https://www.tideking.com.

The interpolation and preparation of plans, corresponding to the topographic and bathymetric surveys, was carried out by applying the Kriging method, with the help of Golden Software Surfer 16.

Plan representation was made using Mercator Transverse Projection, with Antigua-1943 map datum, from British West Indies Grid Coordinates System.

Spatial representation of the topographic survey in the plan used either level curves or isohypses, represented at 0.5-m intervals of vertical variation. Likewise, isobaths were represented at 1.0-m intervals. Customized chromatic scales were designed for the representation. Heights and depths were referred to the mean sea level.

III.3 Laboratory Analysis.

Grain size and composition analyses of the sand were performed in situ by means of a field laboratory. Grain size analysis was done manually, through the dry sifting method, using a set of sieves belonging to Retsh As 200 equipment with mesh sizes of 0.063, 0.125, 0.25, 0.50, 1, 2 and 4 mm (Photo 4).

Sieve weight data were processed with Gradistat Version 8.0, software developed by Simon Blott, from the Department of Geology of the Royal Holloway University of London (Blott, 2001), obtaining the mean particle diameter (M) in mm and ø units, and the standard deviation. For sediment classification, it was used the scale proposed by Wentworth (Shore Protection Manual, 1984) (Table 2).

The composition analysis was done after the grain size processing, taking into account the methodology by Avello and Pavlidis (1975) (Photo 5).

Photo 4: Sand samples were sifted for grain size analysis using a set of sieves belonging to the Retsh As 200 electronic sieve shaker.

Table 2: Wentworth Classification.

ASTM Mesh	mm Size	Phi Value	Wentworth Classification	
			BOULDER	
	256.0	-8.0		
	76.0	-6.25	COBBLE	
	64.0	-6.0		
	19.0	-4.25	PEBBLE	
4	4.76	-2.25		
5	4.0	-2.0		
			GRAVEL	
10	2.0	-1.0		
			very coarse	SAND
18	1.0	0.0		SAND
			coarse	SAND
25	0.5	1.0		SAND
40	0.42	1.25	medium	SAND
60	0.25	2.0		SAND
			fine	SAND
120	0.125	3.0		SAND
200	0.074	3.75	very fine	SAND
230	0.062	4.0		
			SILT	
	0.0039	8.0		
			CLAY	
	0.0024	12.0		
			COLLOID	

Fractions 2-1, 1-0.5 and 0.5-0.25 mm were chosen for this analysis. Subsequently, under the microscope, from each of these fractions, 200 grains are randomly taken and separated into the different groups according to their morphological characteristics. Later, the percentage of each group with regard to the sample total is obtained.

Photo 5: Analysis of sand samples under the microscope in the field laboratory. Grain size and composition analyses were performed on sand samples from Runaway Bay and the proposed borrow area.

III.4 Time Series Analysis.

III.4.1 Time Series.

During the research, the following time series were used:

- Three-hourly series of wind speed and direction corresponding to BARA9 station, located on the west coast of Barbuda. Period 2012-2016 (Data Buoy Center).
- Three-hourly series of Wave Direction, Significant Height and Peak Period, corresponding to the oceanographic buoy 41040, located about 900 km to the ESE of Antigua and Barbuda, in the Atlantic Ocean. Period 2006-2021 (Data Buoy Center).
- Time series of tropical cyclones from 1950 to 2021 (Atlantic Reanalyze Project, NOAA).

III.4.2 Probabilistic Analysis.

The series of wind speed and significant wave height and peak period were adjusted to a Gumbel maxima distribution, by means of a linear function of the type:

$$\lambda = X_P + \delta Ln[-Ln(F_P)] \qquad (1)$$

The probability equivalent to 50% was assumed as representative of the Mean Regime, and values exceeded only 12 hours a year were calculated, in correspondence with the same adjustment equation obtained.

In the case of wind, frequency matrixes were conformed for coincidences of speed and direction ranges, as well as for speed and time of day, direction and time of day, and speed and month of the year.

III.4.3 Storm Waves.

The extreme event series was conformed from wind records during the passage of tropical cyclones by the quadrant delimited by the parallels 15°28'48" LN and 18°48'36" LN, and the meridians 60°07'12" LW and 63°35'24" LW, so that the distance from the study area to each side of the polygon is approximately 100 nautical miles.

Once conformed, the series was also adjusted through a linear function, a Gumbel maxima probabilistic distribution, obtaining the wind values generated by a tropical cyclone, with return periods equivalent to 10 and 100 years.

The procedure used to calculate the wave generated by hurricanes is described in USA - CERC (1977). It is based on an empirical method proposed by Sverdrup, Munk and Bretschneider (SMB Method, described in the same source), used for short ranges and high wind speeds. (Bretschneider, (1959), according to Aldeco, J. and Montaño-Ley, Y., (1986)).

The estimation of the significant wave height and its associated period, at the point of maximum winds, was carried out using the following equations:

$$H_{(S)máx} = 5.03e^{(\frac{R\Delta p}{4700})}[1 + \frac{0.29\propto V_F}{(U_R)^{1/2}}] \qquad (2)$$

$$T_{(P)máx} = 8.6e^{(\frac{R\Delta p}{9400})}[1 + \frac{0.145\propto V_F}{(U_R)^{1/2}}] \qquad (3)$$

where:

$H_{Smáx}$: Significant wave height (m) in deep waters, corresponding to the zone of maximum development within the hurricane.

$T_{Pmáx}$: Peak Period (s) of the wave in deep waters, corresponding to the zone of maximum development within the hurricane.

R: Radius of maximum winds (Km).

ΔP: Difference between the pressure in the eye of the hurricane, and the standard surface pressure (1013.25 mb).

V_F: Travelling speed of the hurricane (km/h).

U_R: Maximum sustained wind speed of the hurricane (km/h).

The same method allows to calculate wave parameters in each sector of a typical tropical cyclone, which was used based on the predicted path and the incident wave direction to simulate (Fig. 5).

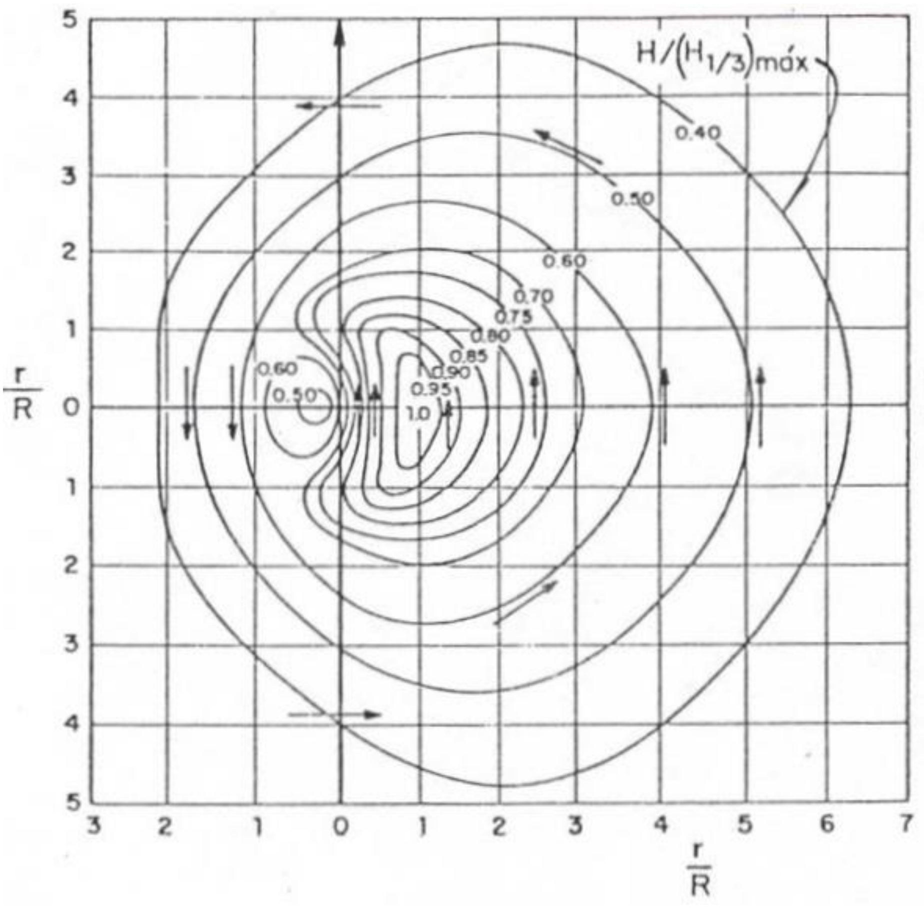


Figure 5: Wave height in relation to the point of maximum height, according to the distance to the circulation center and maximum wind radius of a tropical cyclone (SMB Method).

III.4.4 Storm Surge.

The mean sea level rise caused by the surge tide can be estimated from the maximum sustained wind speed and the maximum wind radius of a tropical cyclone, applying a parametric method.

Based on the analysis of measurements of the surge tide rise generated for some tropical cyclones in the USA and Japan, it was obtained the following expression to determine the maximum amplitude of the surge tide due to a tropical cyclone:

$$\mathrm{h} = \left(0.03\mathrm{R} + 0.000119{U_R}^2 - 1.4421\right)\mathrm{F} \qquad (4)$$

where:

h: Highest rise (m) reached by the surge tide in the coastal area.

R: Radius of maximum winds (Km).

U_R: Maximum sustained wind speed (km/h).

F: Correction factor according to wind direction.

The correction factor (F) is determined from the angle "α" formed by the direction of the tropical cyclone path with regard to the shoreline close to the targeted site. This factor is determined by the expression:

$$\mathrm{F} = \begin{cases} 0.6(1 + \mathrm{sen} \propto) & \mathrm{si}\ \ 0° < \propto < 180° \\ 0.6 & \mathrm{en\ otros\ casos} \end{cases} \qquad (5)$$

III.5 Numeric Simulation.

III.5.1 MOPLA.

To simulate the behavior of incident wave, coastal currents and coastal sediment transport, it was applied the MoPla model, designed by the Oceanographic and Coastal Engineering Group (GIOC) of the University of Cantabria (UC).

The comprehensive “Beach Morphodynamics” model (MoPla) allows to simulate, in the coastal zone, wave propagation from indefinite depths to the shoreline. From this wave, the calculation of induced currents in the breaking zone is done, and finally, the sediment transport in the coastal area is simulated.

The simulations used the package for the propagation and simulation of spectral wave effects in an Oluca-SP beach, parabolic propagation model of spectral, non-dispersive wave, and phase resolution.

The model requires as input in the outer contour (offshore), a directional sea condition represented by a two-dimensional spectrum discretized in frequency and directional components that will be propagated simultaneously. For the propagation of the energy components, the parabolic approximation includes refraction-diffraction with wave-current interaction. To estimate the energy losses due to wave breaking, the statistical dissipation model of Thornton and Guza (1983) was used, which is included in the Oluca-SP.

Once the wave spectrum was generated and propagated to the coastal zone, the Model of Currents in beaches induced by spectral wave breaking (Copla-SP) was applied, which solves the averaged motion equations and the continuity equation within the breaking zone.

Finally, the Eros-SP model (Model for Erosion-sedimentation and bathymetry evolution in beaches due to spectral wave) was run, which solves the equations of sediment flow within the breaking zone, as well as the changes in the bathymetry associated to the spatial variations of sediment transport, taking as input data the outputs of Oluca-SP and Copla-SP, and sediment characteristics in the coastal zone. This model allows characterizing sediment transport due to coastal currents in the coastal zone.

III.5.2 Data Input to the model.

Data resulting from the topographic and bathymetric surveys are entered in the model. The surface is obtained through interpolation done by Kriging method (The SMC uses Surfer calculation engines).

The required nested grids are configured with the highest possible resolution, according to the availability of information and the own boundaries of the model. The basic information of the grids used for simulations corresponding to the case study is shown in Table 3 and Figures 6 to 9.

Table 3: Grids used in numeric simulations. In red the lowest resolution grids, and in black the detailed chained grids.

Grid ID	Origin Coordinates		Azimuth	Length		Spacing		Nodes	
	X	Y		Length X	Length Y	X	Y	X	Y
NNE 60	413950.00	1897495.00	72.5	1380	1980	60	60	24	34
NNE 1/3	414364.97	1896178.87	72.5	2060	1500	20	20	104	76
NNE 1/4	414364.97	1896178.87	72.5	2055	1500	15	15	138	101
N 60	413200.00	1897100.00	62.5	1620	2100	60	60	28	36
N 1/4	414160.91	1895773.86	62.5	1770	1860	15	15	119	125
NW 60	412000.00	1895500.00	35.0	2220	3120	60	60	38	53
NW 1/4	414369.15	1895013.05	35.0	1035	2160	15	15	70	145
W 60	412000.00	1894200.00	0.0	2940	3900	60	60	50	66
W 1/3	414940.00	1894740.00	0.0	1100	1800	20	20	56	91
W 1/4	414940.00	1894740.00	0.0	1710	2940	15	15	115	197

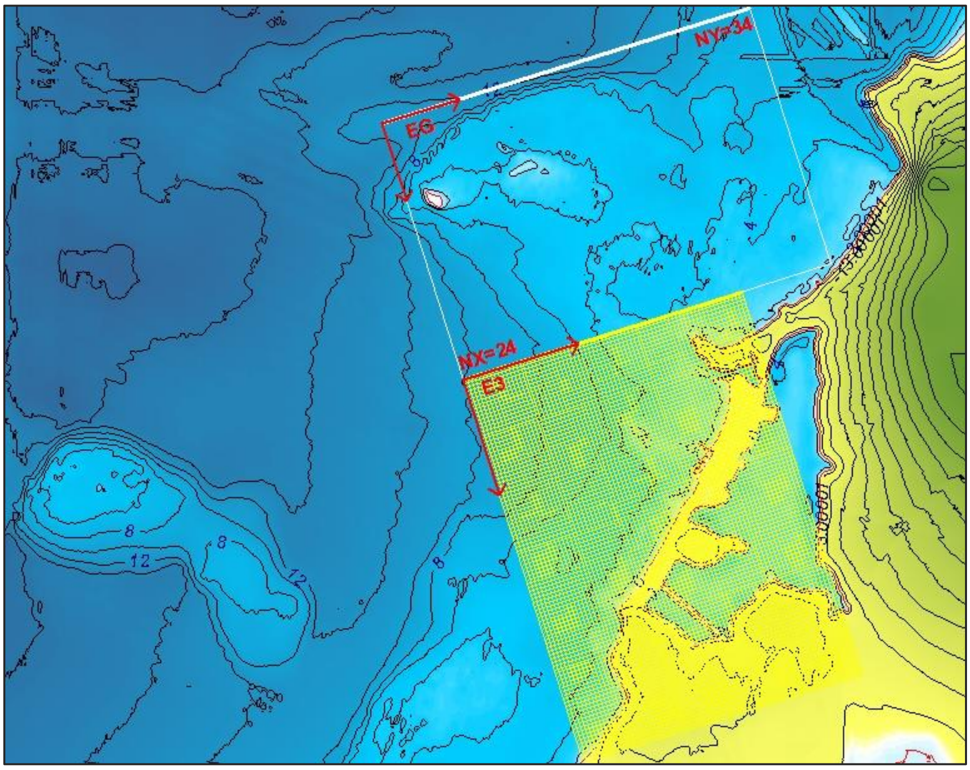


Figure 6: Grids NNE 60 and NNE 1/3, used to simulate the propagation and transformation of incident wave from NNE, as well as wave-induced currents and coastal transport.

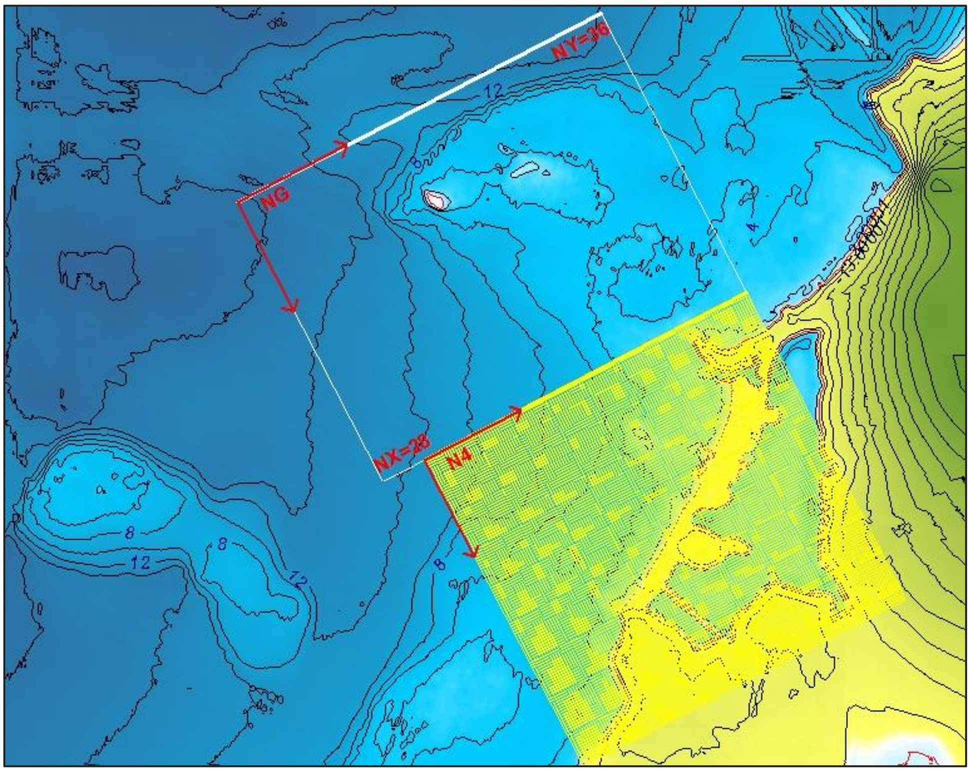


Figure 7: Grids N 60 and N 1/4, used to simulate the propagation and transformation of incident wave from the north, as well as wave-induced currents and coastal transport.

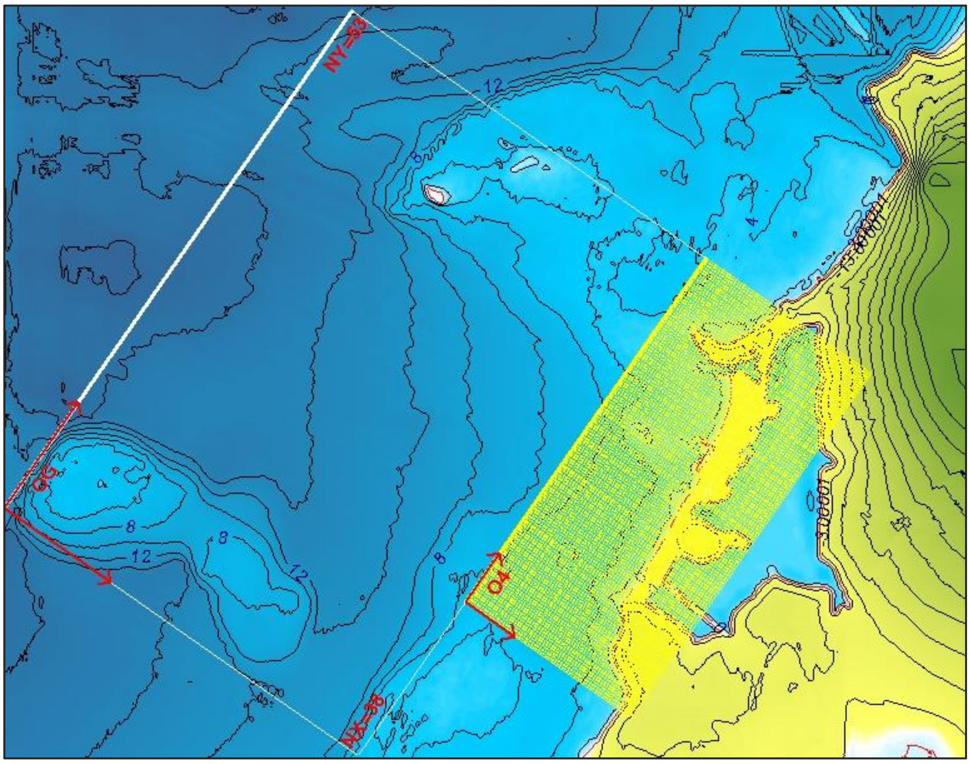


Figure 8: Grids NW 60 and NW 1/4, used to simulate the propagation and transformation of incident wave from the NW, as well as wave-induced currents and coastal transport.

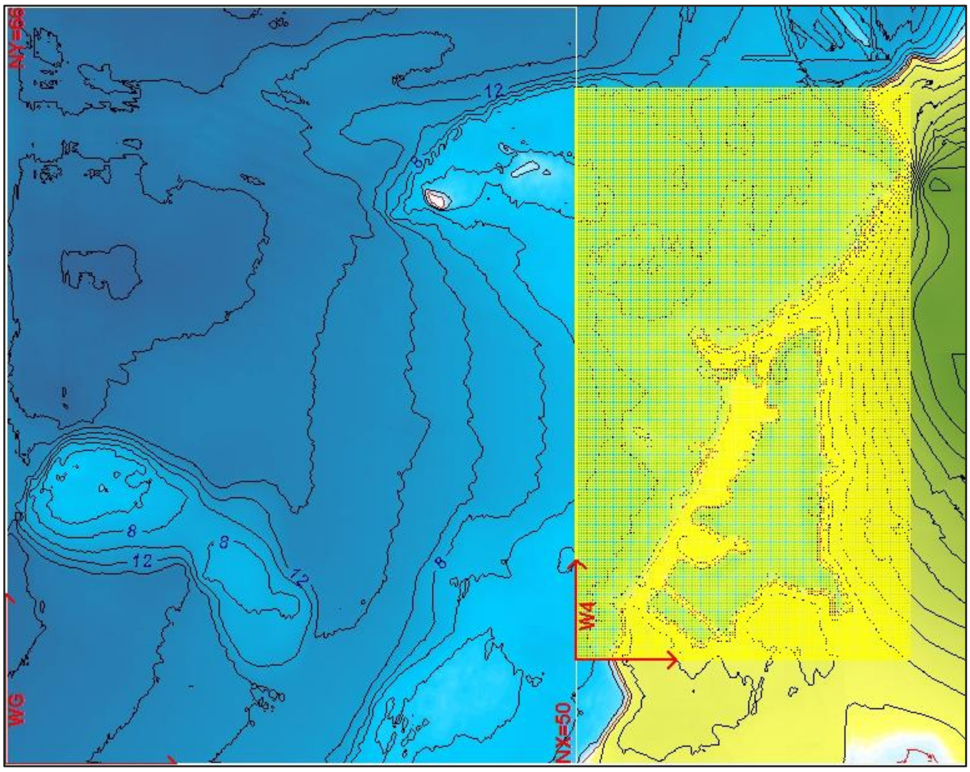


Figure 9: Grids W 60 and W 1/4, used to simulate the propagation and transformation of incident wave from the W and the SW, as well as wave-induced currents and coastal transport.

In the definition of cases to be simulated, certain parameters remained constant:

With the input to Hs values, it was estimated a spectrum composed of Texel Marsen Arsloe (TMA), with distinct number of components according to the simulated event. The TMA spectrum is defined from a JONSWAP spectrum and applied in zones close to the coast, in mean depths where waves are affected by the seabed, which is taken into account by the dimensionless function proposed by Hughes (1984). All the above is automatically calculated by the system.

The parameters of the spectrum, and of directional dispersion of Borgmann function (1984), as well as the number of directional components, were also defined based on the type of simulated event.

We worked with a tidal amplitude equal to 0.30 m, a value greater than 99% of those recorded in 10 years, during the period 2012-2021, at station 9761115, in Barbuda (Fig. 10) (https://tidesandcurrents.noaa.gov/).

The recommended models by Thornton and Guza were applied for dissipation due to breaking and of turbulent limit layer for the dissipation by seabed, considering open the lateral contours of the grid.

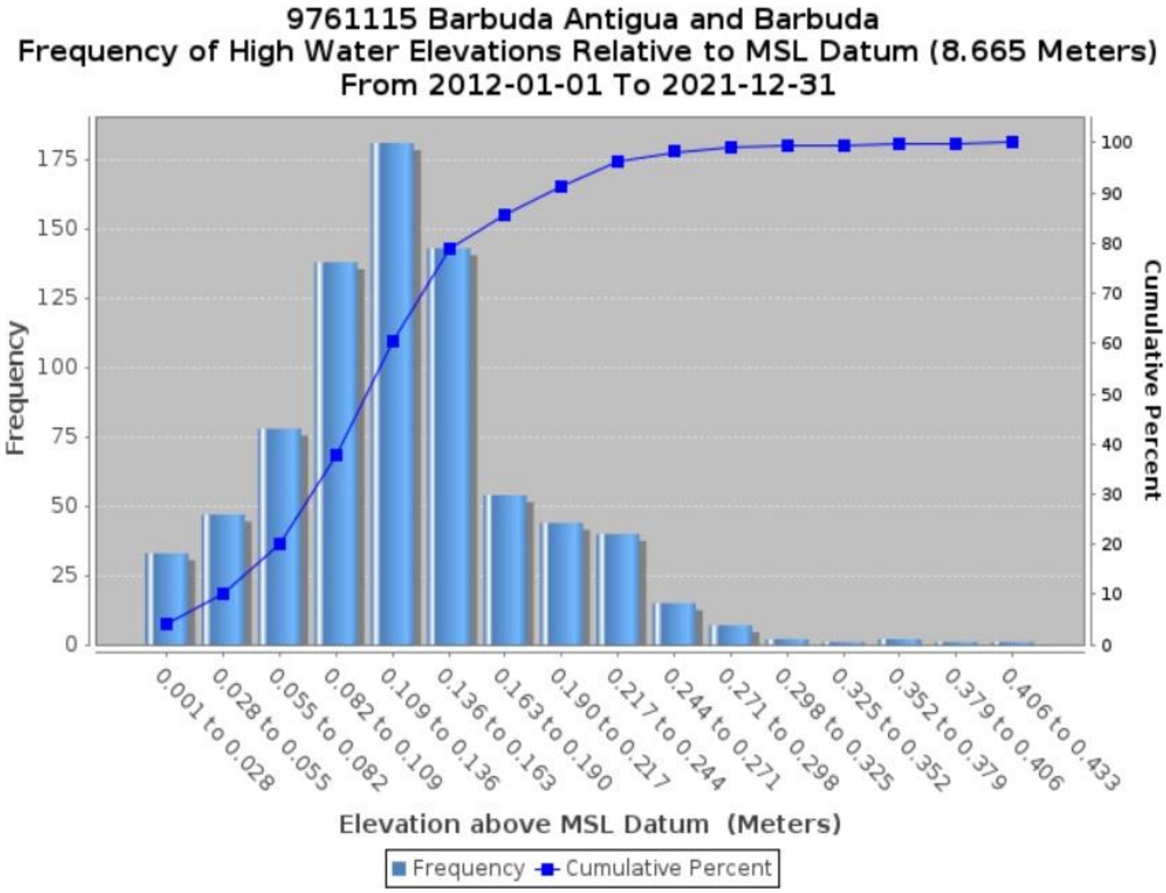


Figure 10: Absolute frequencies of the different ranges of sea level rise (m) above its mean level, at station 9761115 , in Barbuda (2012-202). Source: NOAA.

Input parameters related to grain size analysis in the laboratory ($D_{(50)}$ =0.248 mm and $D_{(90)}$ =0.587 mm), were obtained by defining a type sample for the emerged beach.

The duration of the simulated event was always of 12 hours, period recommended by the authors of the model, to achieve stability in the results, without demanding a very high computational cost. In the rest of the parameters requested by the model, we worked with the values recommended by its authors.

III.6 Project Design.

III.6.1 Equilibrium Profile.

For the calculation of the equilibrium profile, it was used the formulation proposed by Bruun (1954) and revised by Dean (1991):

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

where:

h(y): Depth at a given distance.

y: Horizontal distance from the shoreline.

A: Dimensionless parameter related to sediment characteristics.

Given the sand composition in the study area, we resorted to the equation proposed by García (2005), for the calculation of parameter A based on the mean particle diameter (D) expressed in millimeters.

$$A = 0.16D^{0.22} \qquad (7)$$

The closure depth of the active profile (h*) was calculated from the equation proposed by Hallermeier (1981):

$$h_* = 2.28H_{s12} - 68.5\left(\frac{{H_{s12}}^2}{g{T_p}^2}\right) \qquad (8)$$

where:

H_{S12}: It is the wave exceeded only 12 hours a year.

T_P: It is the corresponding peak period.

g: Gravity acceleration constant (9.81 m/s2).

III.6.2 Fill Volume.

The fill volume was calculated from the method proposed by Dean (1991) based on a “reverse” application of Bruun's Rule (1962).

According to this method, when the berm height is B and the closure depth is h*, to achieve an increase in beach width Y, a volume V of sediments will be required per shoreline length unit (Fig. 11 and 12), given by the expression:

$$V = Y(B + h_*) \qquad (9)$$

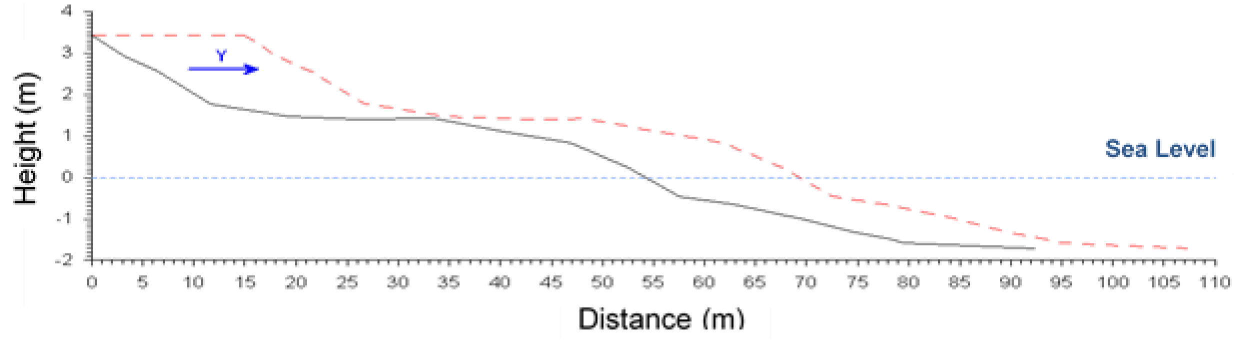


Figure 11: Offshore displacement of the active profile as a consequence of the sand fills.

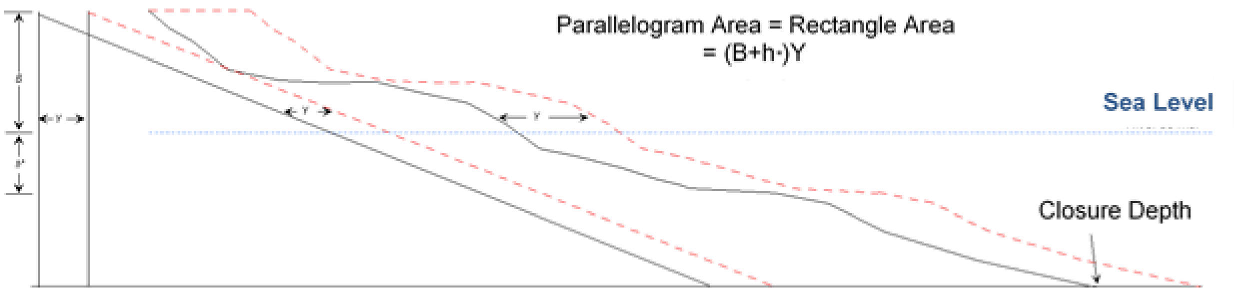


Figure 12: Volume of sand per shoreline length unit resulting from beach filling.

For the case where the grain size of the introduced sediment differs from the size of the native sediment, Dean's method (1991) allows determining the volume of sediments necessary to achieve the desired dry beach width.

Dean (1991) defines three basic types of nourished profiles: profiles that intercept, where the nourished profile intercepts the native one; profiles that do not intercept, where the nourished profile never intercepts the native one before the closure depth; and submerged profiles.

To determine whether or not a profile intercepts, Dean (1991) reaches the following inequalities:

$$Y\left(\frac{A_N}{h_*}\right)^{3/2} + \left(\frac{A_N}{A_F}\right)^{3/2} < 1 \qquad profiles\ intercepted \tag{10}$$

$$Y\left(\frac{A_N}{h_*}\right)^{3/2} + \left(\frac{A_N}{A_F}\right)^{3/2} > 1 \qquad profiles\ not\ intercepted \tag{11}$$

Where:

A_N: Valor Value of the scale parameter A of the native sand.

A_F: Value of the scale parameter A of the introduced sand.

h_*: Closure depth of the active profile.

Y: Beach width to increase.

When the profiles do not intercept, the sediment volume to be filled in order to obtain a given beach width is determined by the expression:

$$V = YB + \frac{3}{5} {h_*}^{3/2} \left[A_N \left[\frac{Y}{{h_*}^{3/2}} + \left(\frac{1}{A_F} \right)^{3/2} \right]^{5/3} - \left(\frac{1}{A_F} \right)^{3/2} \right] \quad (12)$$

Where:

V: Sediment volume in cubic meters per linear meter of beach (m^3/m).

B: Berm height (m).

When the profiles intersect, the sediment volume to be filled in order to obtain a given beach width is determined by:

$$V = BY + \frac{\frac{3}{5} A_N Y^{5/3}}{\left[1 - \left(\frac{A_N}{A_F} \right)^{3/2} \right]^{2/3}} \quad (13)$$

III.6.3 Overfill ratio.

The overfill ratio RA was calculated according to the methodology proposed by James (1975) and recommended in the Shore Protection Manual (1984) and the Manual on Artificial Nourishment (1987).

Based on the results of the grain size analysis of sand samples collected in the borrow area and the beach, abscissa and ordinate values are calculated for their representation in the Abacus obtained by James (1975) (Fig. 13).

$$Abscissa = \frac{M_{\emptyset b} - M_{\emptyset n}}{\sigma_{\emptyset n}} \quad (14)$$

$$Ordinate = \frac{\sigma_{\emptyset b}}{\sigma_{\emptyset n}} \quad (15)$$

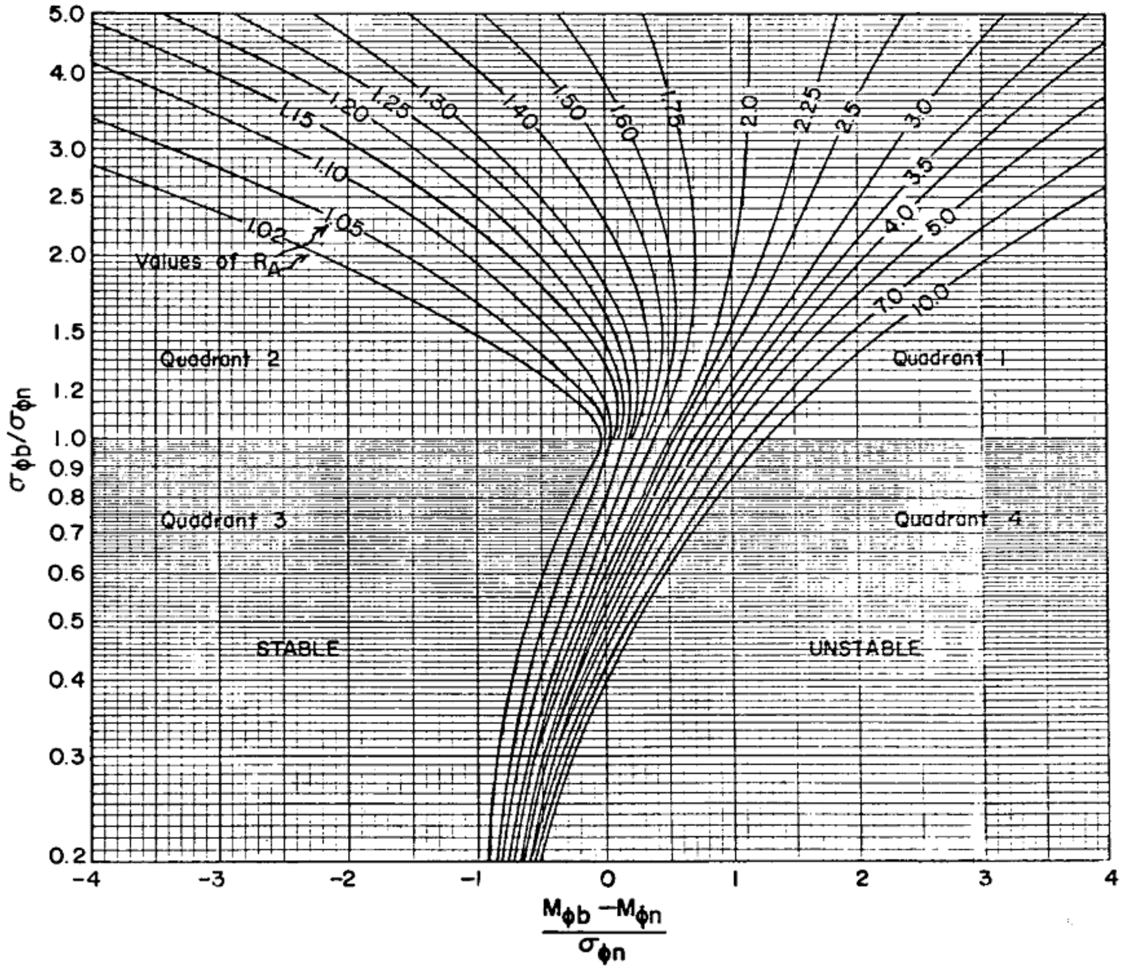


Figure 13: Overfill ratio R_A according to James (1975).

IV. PHYSICAL-GEOGRAPHICAL CHARACTERISTICS

Antigua and Barbuda is a country made up of two islands of the Lesser Antilles in the Eastern Caribbean (Fig. 14), with a combined total area of 440 km^2 (including others smaller islands) and a population estimated at 97,000 inhabitants in 2019.

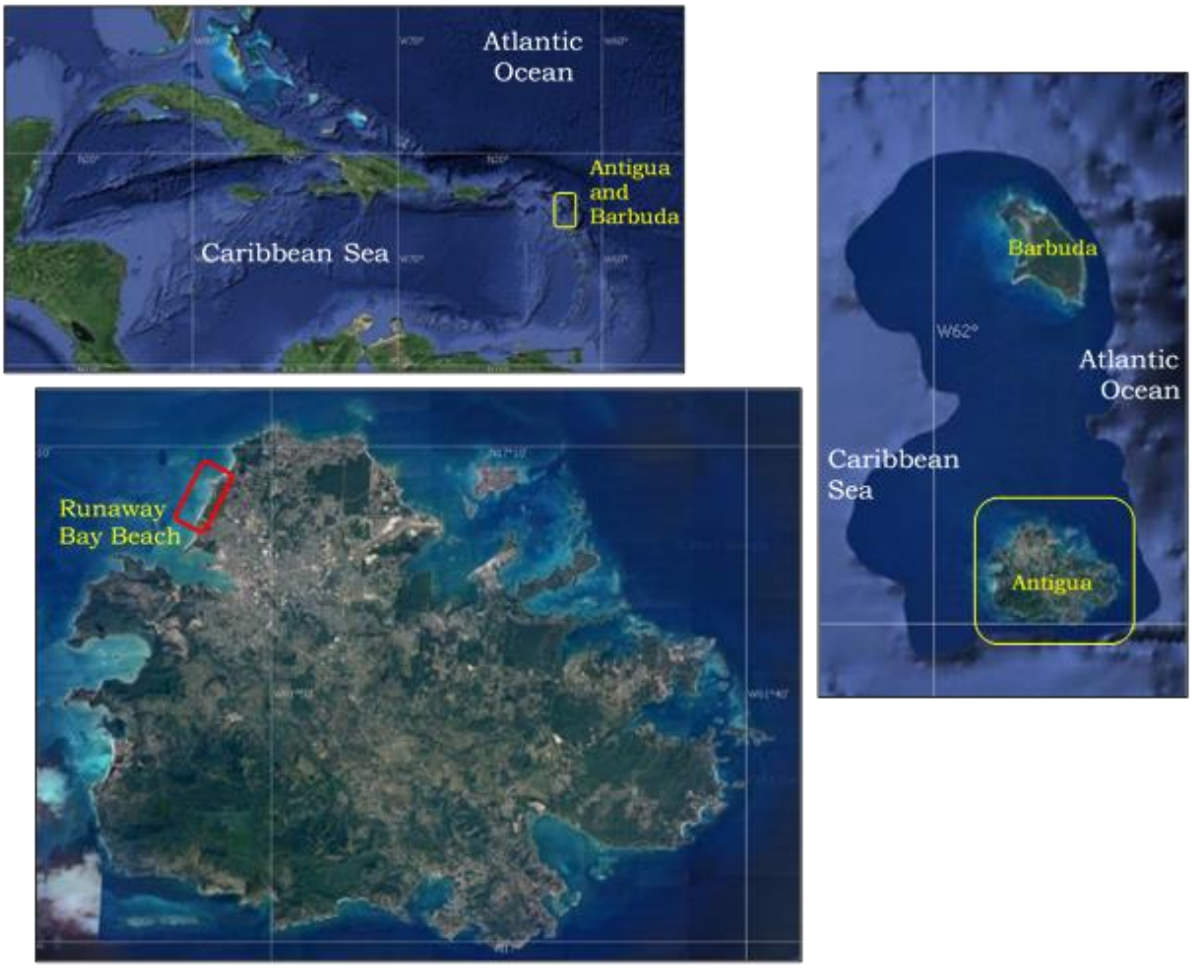


Figure 14: Geographic location of Antigua and Barbuda and the case study: Runaway Bay Beach.

Both islands possess a common submerged shelf, relatively extensive, of about 80 km from north to South, by 40 km from east to west, with depths that rarely surpass 30 m.

Their eastern coast receives the direct impact of waves that move on the surface of the Atlantic Ocean, while the west coast gives way to the Caribbean Sea.

Antigua island has a mixed volcanic and marine origin, though with marked predominance of the latter in the northern part, where Runaway Bay is located.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

IV.1 General Characteristics and Main Elements.

Runaway Bay Beach is located in the NW region of Antigua Island, oriented from SSW to NNE, with an azimuth of 28° and an extension of approximately 1,300 m.

Given its geographical location and shoreline orientation, its waters are open to the Caribbean Sea, but notably protected from waves coming from the Atlantic Ocean, whose regime is predominant in the study area, thus favoring that the beach exhibits a gently sloping profile and medium to fine sand.

The beach itself is a large sand bar – highly anthropized at present and partly the object of technical fill works for the construction of structures and a road – probably emerged in more favorable moments for the occurrence of sediment accretion processes, separating the sea waters from a coastal lagoon, named McKinnon's Salt Pond (Photo 6) (whose environmental values, and their deterioration, would require a separate study and project).

Runaway Bay limits to the north with the access channel to a Marina Bay, which separates it from the rocky ledge of Corbisson Point and Dickenson Bay beach. To the south, a cliff separates it from Fort Bay beach (Plan 1).

Photo 6: Panoramic view of a central sector of McKinnon's Salt Pond

On a first inspection, the sandy sediments that make up these beaches have an eminently biological origin, with certain inorganic components, coming from of abrasion process of the adjacent cliffs, such as those that can be seen in Photos 7 and 8.

At Runaway Bay Beach, a high level of anthropization was observed, mainly in the north sector, with several buildings occupying the zone coastal (Photo 9), as well as coastal defense structures in the north and central sectors (Photo 10).

At various points along the coast, with the greatest recurrence immediately south of the coastal defense structures, some rocky outcrops and an old scarp can be observed on the front face of the dune. They are evidence of an erosion process, probably moderate in a first evaluation, considering only these elements (Photo 11). However, as previously mentioned, a more detailed review of the bibliography allows to define the original extension of the beach northwards and to understand that this sector he has undergone an intense erosion process.

Photo 7: Cliff in the north end of Dickenson Bay beach. This type of structures are also frequent along the northwest coast of Antigua.

Photo 8: Rocky ledge located between the beaches of Dickenson Bay and Runaway Bay, in the north end of the latter. Currently, between the ledge and the beach, there is the access channel to Marina Bay, which was dredged in the last decades of the 20th century.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

Photo 9: The north sector of Runaway Bay Beach is very anthropized since the late 1980s and beginning of the 1990s. An intense erosion process associated to the impact of tropical cyclones, which made the beach disappear in this sector dates back just to that time.

Photo 10: The central sector of Runaway Bay is occupied by buildings and coastal defense works.

Photo 11: Immediately south of the coastal defense structures, in the central sector of Runaway Bay Beach, rocky outcrops are visible in the surface of the beach and the bathing area.

In others aspects, the decrease in water circulation behind the mentioned defense structures has caused the stiffening of the submerged profile and has contributed to the eutrophication of stagnant water, almost like in an artificial lagoon (Photo 12).

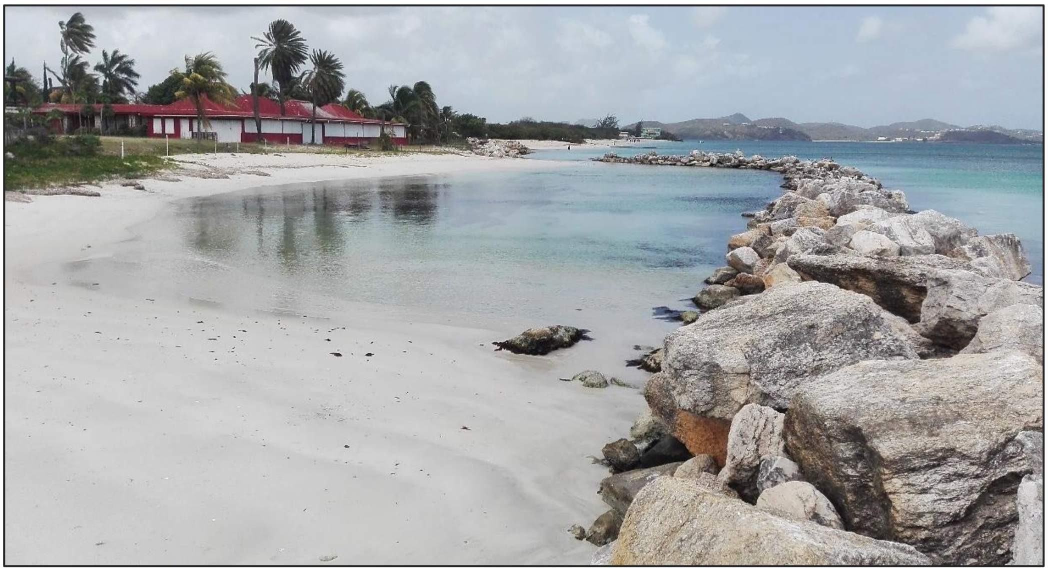


Photo 12: Behind the coastal defense structures in the central sector of Runaway Bay Beach, the low water circulation has caused eutrophication, proliferation of seagrasses and seabed stiffening.

Also, in the dune and post-dune area not occupied by buildings, the natural vegetation has been displaced, almost entirely, by invasive species (Photo 13).

Photo 13: In the central-south sector of Runaway Bay Beach, native vegetation has been almost completely replaced by invasive species.

IV.2 Geomorphology.

The topographic survey covered an area of 170,000 m^2 in Runaway Bay, taking measurements at 1,529 points (Fig. 15).

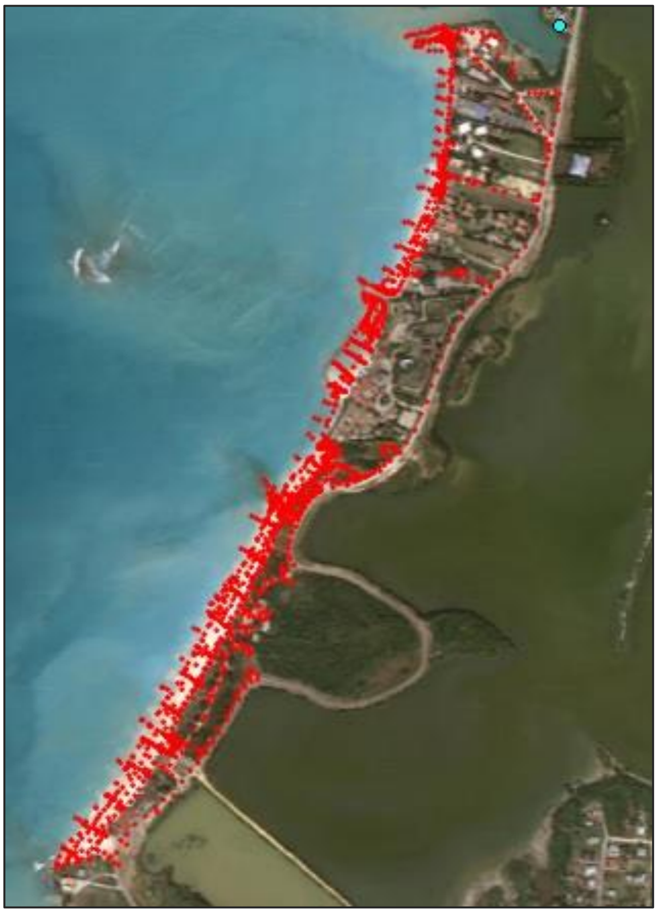


Figure 15: Survey points measured in the study area.

The outstanding elements identified in the study area and its vicinity, like submarine wires, pipelines for fuel discharge, buildings and coastal defense structures, are shown in Plan No. 1, and in more detail, in Plan No. 1A. A graphic representation of the height of the different elements in the terrain, with respect to mean sea level, can be seen in Plan No. 2.

As a result, clear differences can be appreciated between the north sector of the beach, highly anthropized, and its southern area that still partly conserves its dunes, even though in its south end they have also been occupied by buildings. Among the anthropogenic elements in Runaway Bay Beach stand out:

- 1 breakwater.
- 2 groynes.
- 185 m of rocky structures (revetments) to defend building foundations and grounds subdivided into 3 sectors.
- 25 buildings occupying the dune or on the first line of the coast.
- 23 buildings located on the second line of the coast.
- 12 buildings located on the third line of the coast.
- Fences and walls for the delimitation of properties.
- Important areas subject to technical filling for the leveling of the land.
- A paved main road and several partly paved secondary roads.

Based on these and other elements, it is possible to subdivide Runaway Bay Beach into four sectors, useful for their study and for the design of action strategies (Plan 1A).

IV.3 Sedimentology.

Nine sand samples were collected on Runaway Bay Beach. According to the results of laboratory analysis, seven of the nine sand samples were classified as fine sand. Only the sand sample taken at the north station (RBB9) was classified as coarse sand. These are elements to consider during the design of the solution.

The results of the grain size analysis of sand samples taken from the beach are summarized in Tables 4 and 5 and in Annex I. Type samples (TS) analysis results, by zone of the beach, are included.

The results of the composition analysis of sand samples taken from Runaway Bay Beach are shown in Table 6.

Table 4: Runaway Bay. Distribution by sample, by sieve.

Samples Runaway Bay Beach	Sieve Ranges							
	>4	4-2	2-1	1-0.5	0.5-0.25	0.25-0.125	0.125-0.063	< 0.063
RBB 1	0	0	0	0.2	17.5	68.7	13.5	0
RBB 2	0	0.2	0.6	1.2	11.4	74.4	12.2	0
RBB 3	0	0	0	0.2	42.6	55	2	0
RBB 4	0	0.2	1.7	7.4	24.8	58.8	6.9	0
RBB 5	0.3	0.6	1.7	7	68.7	18.7	2.8	0
RBB 6	0	0	0.5	2.4	12.5	69.7	14.9	0
RBB 7	0	0	0.1	0.3	9.8	61.6	28.1	0
RBB 8	0	0	0.7	2.7	16.7	73.6	6.2	0
RBB 9	1.6	10.1	22.7	19.7	32.8	10.9	2	0
TS RB North	1.60	10.10	22.70	19.70	32.80	10.90	2.00	0.00
TS RB Center	0.00	0.07	0.20	0.53	23.83	66.03	9.23	0.00
TS RB South	0.06	0.16	0.94	3.96	26.50	56.48	11.78	0.00

Table 5: Runaway Bay. Main statistics and classification according to grain size.

Samples Runaway Bay Beach	Percentiles		M		Statistics			Classification
	D50	D90	(mm)	(Ø)	Standard Dev. (Ø)	Asymmetry	Kurtosis	
RBB 1	0.181	0.339	0.182	2.455	0.561	-0.090	3.357	Fine Sand
RBB 2	0.178	0.307	0.182	2.457	0.606	-1.499	10.127	Fine Sand
RBB 3	0.229	0.426	0.235	2.089	0.535	-0.009	1.934	Fine Sand
RBB 4	0.208	0.491	0.231	2.113	0.806	-1.052	4.600	Fine Sand
RBB 5	0.333	0.498	0.328	1.609	0.726	-0.849	8.388	Medium Sand
RBB 6	0.177	0.337	0.182	2.460	0.642	-0.970	5.987	Fine Sand
RBB 7	0.160	0.254	0.157	2.673	0.606	-0.305	3.575	Fine Sand
RBB 8	0.189	0.380	0.200	2.319	0.606	-1.380	6.926	Fine Sand
RBB 9	0.580	2.251	0.647	0.629	1.306	-0.176	2.361	Coarse Sand
TS RB North	0.580	2.251	0.647	0.629	1.306	-0.176	2.361	Coarse Sand
TS RB Center	0.192	0.383	0.198	2.334	0.594	-0.512	4.969	Fine Sand
TS RB South	0.200	0.440	0.212	2.235	0.772	-0.884	5.289	Fine Sand

Table 6: Results of the composition analysis of sand samples from Runaway Bay Beach.

Composition of Sand Samples from Runaway Bay Beach						
Sand Sample	**Calcareous Algae (%)**	**Mollusks (%)**	**Foraminifera (%)**	**Bioclasts (%)**	**Inorganic Remains (%)**	**Other groups (%)**
RB 1	70.8	17.7	2.7	7.5	0.5	0.7
RB 2	74.3	13.4	2.0	7.9	2.0	0.3
RB 3	65.3	21.0	4.2	7.7	1.0	0.8
RB 4	70.7	14.2	4.2	5.6	5.0	0.3
RB 5	71.4	14.6	4.2	4.8	4.1	0.8
RB 6	73.6	15.5	2.4	5.1	2.9	0.5
RB 7	72.9	12.4	4.7	5.9	3.1	1.0
RB 8	78.2	10.8	2.0	4.1	4.1	0.8
RB 9	68.4	15.5	3.0	4.6	7.8	0.6

Images under the microscope of grain selected according to their composition, parts of the sand samples taken from Runaway Bay are shown in Photos 14 to 17.

Photo 14: Grains of biogenic sand under the microscope. Sample taken at Runaway Bay. Skeletal remains of Halimeda algae.

Photo 15: Grains of biogenic sand under the microscope. Sample taken at Runaway Bay. Remains of mollusks shells.

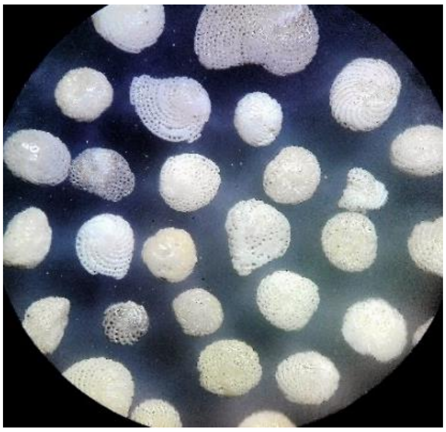


Photo 16: Grains of biogenic sand under the microscope. Sample taken at Runaway Bay. Skeletal remains of foraminifera.

Photo 17: Grains of inorganic sand under the microscope. Sample taken at Runaway Bay. Tiny grains of quartzite, and even ferrous materials, from abrasion of adjacent cliff and rocky ledges.

The results allow to determine that the sand samples taken at Runaway Bay are mostly biogenic, with a small percentage of remains of mineral and terrigenous origin. The group of calcareous algae (Halimeda) remains is the majority in nine samples analyzed, followed by mollusks remains, unidentified bioclasts and foraminifera, with inorganic remains appearing in a lower percentage. Other groups include organisms that due to their abundance are not representative in the samples, such as sponge spicules, annelids, bryozoans, etc.

In the nine samples analyzed, the sand has a light beige color, only RB 9 is a little darker because it includes more abundant grains of terrigenous origin; the grains are polished and with sub-rounded edges due to being exposed to weathering and wave.

IV.4 Bathymetry.

The bathymetric study consisted of measuring 86 sounding lines, perpendicular to the coast and measured every 50 m, to depths close to 20 m (Fig. 16).

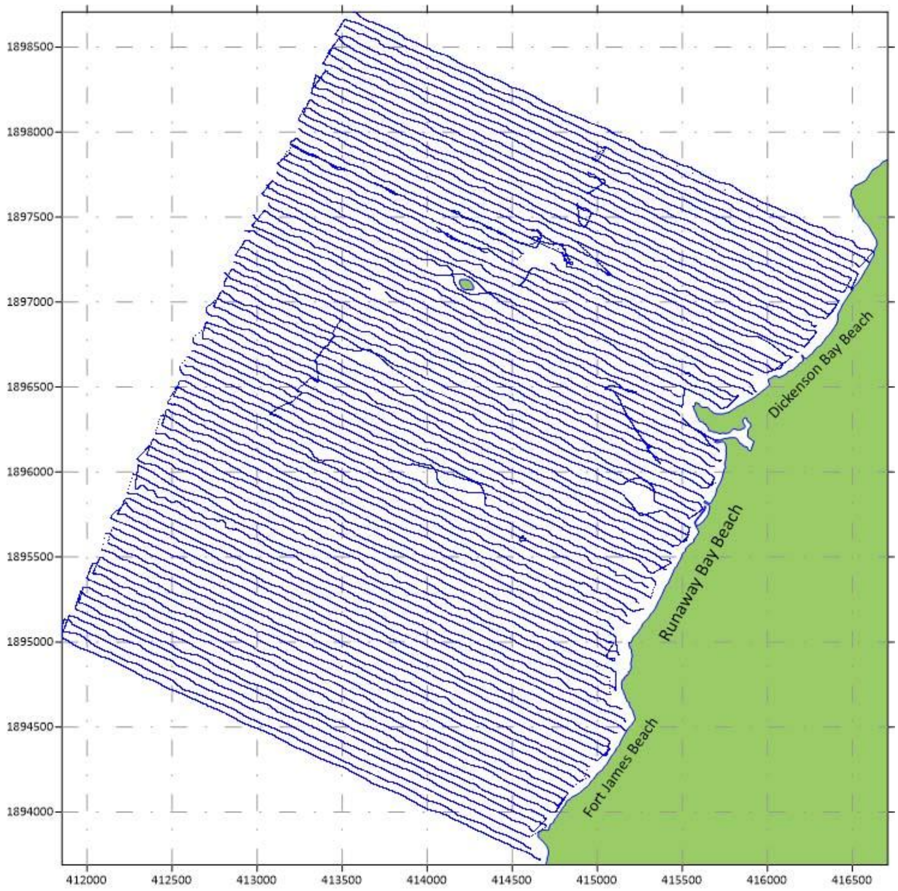


Figure 16: Sounding lines and points measured during the bathymetric survey.

The total study area reached 12.8 km^2 , spreading from the SW end of Fort Bay Beach, located south of Runaway Bay, to the NE end of Dickenson Bay Beach, located north of Runaway Bay. It extended seawards to a distance of 3.1 km from the coast, encompassing the area where it was identified the existence of an accretion of sandy sediments, with potential to be used as borrow area for the application of artificial sand nourishment, if necessary.

During the studies, it was observed that the submarine slope presents irregular areas that were recorded on bathymetric profiles. It was also observed the existence of shallow areas where rocky bodies appear in the form of reefs, which emerge in the low tide, and in some cases forced us to divert the boat path or to measure the sounding lines discontinuously.

A graphic representation of the depths of seabed surface with regard to mean sea level, on the shoreline of Runaway Bay Beach, can be appreciated in Plan No. 3.

IV.5 Sectorization and outstanding elements.

Plan 1A allows to observe in greater detail the outstanding elements in the beach, as well as a sectorization proposal for it, that will be used in the present study.

The proposed sectors are numbered 1 to 4 from south to north:

- **Sector 1:** It is the least anthropized and most extensive. It can be further subdivided into three sections: the south end, more cumulative presumably due to the usual littoral drift, despite the fact that the dune is occupied by constructions; the central area, where the best preserved dune sectors are found, although it should be noted a high cover degree of invasive plant species; and the north area, where the sun strip narrows and a certain number of rocky outcrops is remarkable.
- **Sector 2:** Completely "protected" by rocky structures in the form of breakwaters and revetments. It begins in the south, with the first rocky structures, and ends in the groyne and pier, located to the north.
- **Sector 3:** Sandy beach leaning to the south, on the breakwater built as a groyne and pier, that extends northwards until once more reaching a coast without sand and protected by rocky structures. Some dune sectors are conserved, but they are anthropized in great measure.
- **Sector 4:** North end where the emerged beach is almost entirely lost. Highly anthropized. The structures in first line of the coast are directly exposed to sea action. It limits to the north with the breakwater in the northern end of the beach, the access channel to Marina Bay and the rocky ledge of Corbison Point.

The type profile and main characteristics of the four sectors in which the beach has been subdivided for this study are shown below in Tables 7 to 12, as well as in Plans 2A, 2B and 2C, and is part of the information resumed in the Plan 8. It is also included the representation of theoretical equilibrium profile calculated according to the method mentioned in III.6.1.

In general, the equilibrium profile is slightly above the measured profile, denoting certain sediment deficit, until it is intercepted by the outcrop of the rocky terrace at depths of 3 m to 5 m. In the case of Sector 2, this difference is more marked, as a result of the undermining effect of wave impact on the breakwater structure.

Something similar happens in the central area of Sector 1 (1B), probably related to the frequent outcrops of the rocky terrace. These are elements that should be considered in the design of the solution.

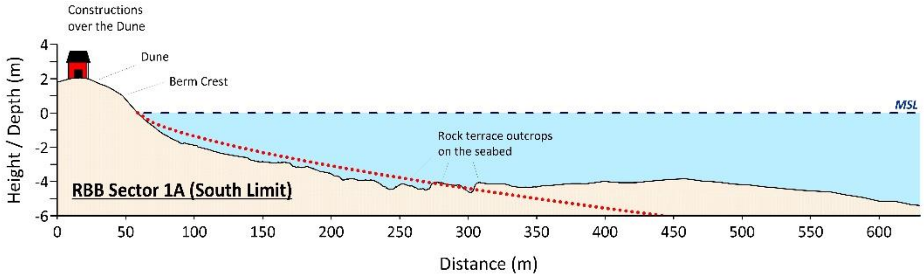
Table 7: Sector 1. Profile 1A. Main characteristic. Equilibrium profile (in red).

SECTOR 1

Profile 1A. Beach with dune occupied by structures.

Reference coordinates

East	North	Height
415306.697	1895058.772	1.801



Characteristics of the sediments:

Sample	Profile	Grain size			Macroscopic Description
		M (mm)	ϕ	Classification	
RBB 8	1A	0.200	2.319	Fine Sand Moderately well sorted	Biogenic sand. Light beige color. Composition: Calcareous Algae, Mollusks and some inorganic materials.

Description:

Well-developed profile, with fine sand, well sorted, approximately 30m-wide sun strip and dune almost totally occupied by hard constructions.

Well defined berm and foreshore with a slightly more pronounced slope than the rest of the beach. Extensive bathing area with sandy seabed. Submerged profile with a soft slope and some outcrops of the rocky terrace.

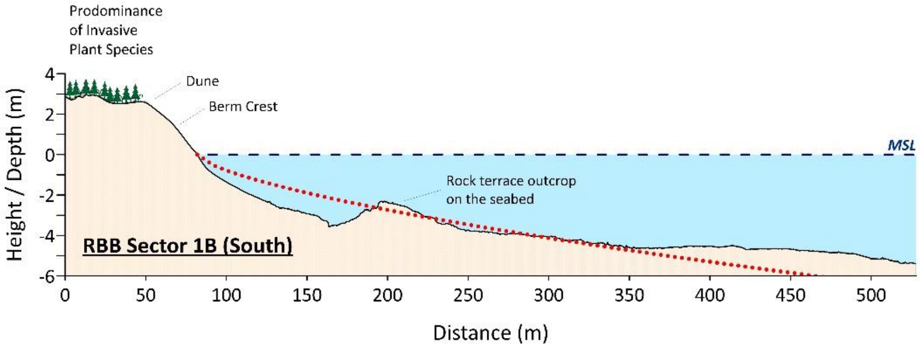
Table 8: Sector 1. Profile 1B. Main characteristic. Equilibrium profile (in red).

SECTOR 1

Perfil 1B. Playa con duna ocupada por especies de plantas invasoras.

Reference coordinates

East	North	Height
415484.060	1895301.833	2.888



Characteristics of the sediments:

Sample	Profile	Grain size			Macroscopic Description
		M (mm)	ϕ	Classification	
RBB 6	1B	0.182	2.460	Fine Sand Moderately well sorted	Biogenic sand. Light beige color. Composition: Calcareous Algae, Mollusks and some inorganic materials.

Description:

Well-developed profile, with fine sand, well sorted, approximately 30m-wide sun strip and dune almost totally occupied by invasive plant species.

Well-defined berm and foreshore with a relatively steep slope. Extensive bathing area with sandy seabed. Submerged profile with a slightly more pronounced slope than in the rest of the beach, with some rocky outcrops.

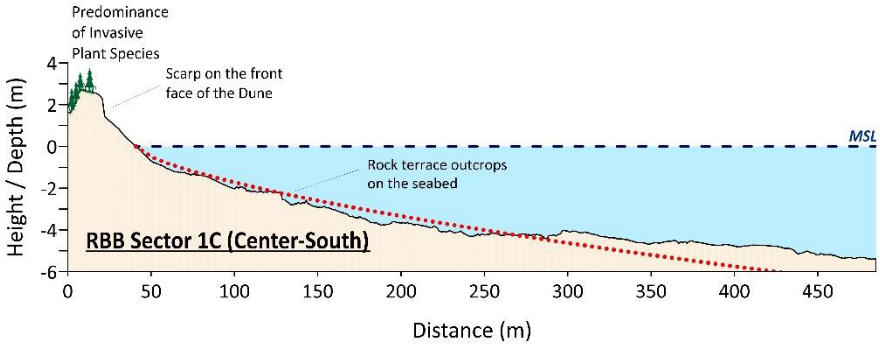
Table 9: Sector 1. Profile 1C. Main characteristic. Equilibrium profile (in red).

SECTOR 1

Perfil 1C. Playa afloramientos rocosos y duna escarpada y ocupada por plantas invasoras.

Reference coordinates

East	North	Height
415561.920	1895527.554	1.624



Characteristics of the sediments:

Sample	Profile	Grain size			Macroscopic Description
		M (mm)	ϕ	Classification	
RBB 4	1C	0.231	2.113	Fine Sand Moderately sorted	Biogenic sand. Light beige color. Composition: Calcareous Algae, Mollusks and some inorganic materials.

Description:

Poorly developed profile, dune scarped on its front face and almost completely occupied by invasive plant species. Fine and well sorted sand. About 20 m of sun strip width.

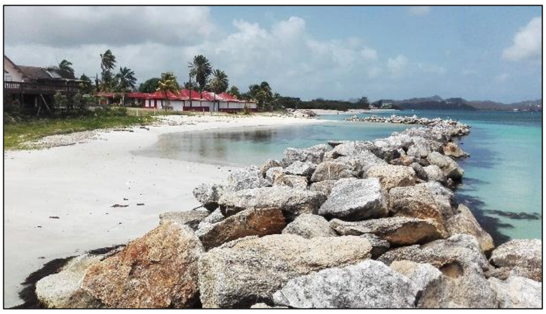
Soft slope foreshore with recurrent rocky outcrops. Extensive bathing area with a mostly sandy seabed. Submerged profile with a slightly more pronounced slope than in the rest of the beach, with some rocky outcrops.

Table 10: Sector 2. Type Profile. Main characteristic. Equilibrium profile (in red).

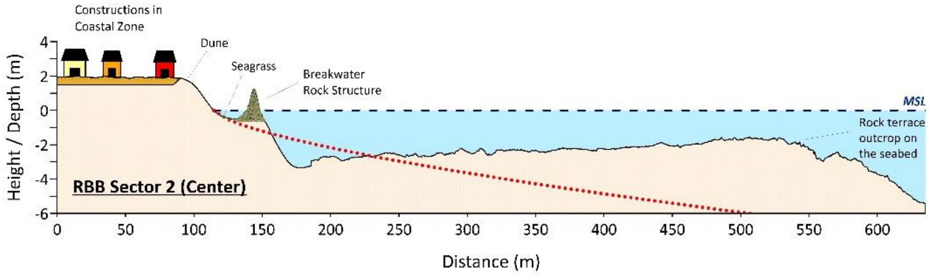
SECTOR 2

Perfil 2. Playa encerrada por escolleras.

Reference coordinates



East	North	Height
415717.347	1895659.822	1.947



Characteristics of the sediments:

Sample	Profile	Grain size			Macroscopic Description
		M (mm)	ϕ	Classification	
Mean of RBB 1, 2 and 3	2	0.198	2.334	Fine Sand Moderately well sorted	Biogenic sand. Light beige color. Composition: Calcareous Algae, Mollusks and some inorganic materials.

Description:

Highly anthropized profile. Rocky coastal defense structures in the form of breakwaters or placed on the frontal face of the dune, and a groyne in its north end. Constructions on the dune and backdune. Beach sheltered by structures that do not allow appropriate water flow, so that eutrophication, growth of seagrasses and seabed stiffening are observed. Seabed with rocky outcrops that condition the relief morphology.

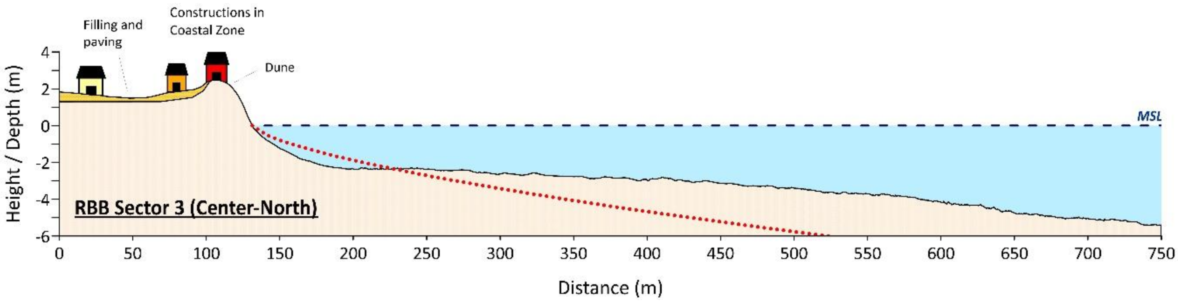
Table 11: Sector 3. Type Profile. Main characteristic. Equilibrium profile (in red).

SECTOR 3

Perfil 3. Playa de muy suave pendiente apoyada en espigón Sur.

Reference coordinates

East	North	Height
415821.576	1895842.009	1.834



Characteristics of the sediments:

Sample	Profile	Grain size			Macroscopic Description
		M (mm)	ϕ	Classification	
Mean of RBB 1, 2 and 3	3	0.198	2.334	Fine Sand Moderately well sorted	Biogenic sand. Light beige color. Composition: Calcareous Algae, Mollusks and some inorganic materials.

Description:

Poorly developed profile. Beach supported on the groyne located in its south end. Dune partly occupied by buildings and invasive plant species. Fine, well sorted sand. Sun strip approximately 15 m to 20 m wide. Foreshore and submerged profile with soft slopes.

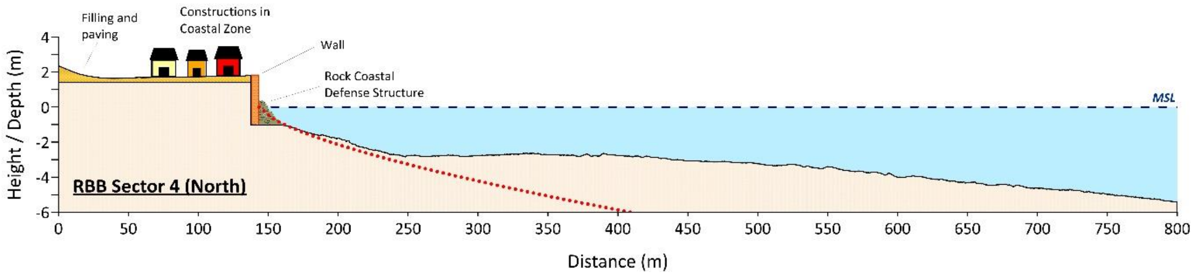
Table 12: Sector 4. Type Profile. Main characteristic. Equilibrium profile (in red).

SECTOR 4

Perfil 4. Antigua playa, perdida por los efectos de la erosión.

Reference coordinates

East	North	Height
415906.069	1896087.861	2.346



Characteristics of the sediments:

Sample	Profile	Grain size			Macroscopic Description
		M (mm)	ϕ	Classification	
RBB 9	4	0.647	0.629	Coarse sand Poorly sorted	Biogenic sand. Dark beige color. Composition: Calcareous Algae, Mollusks and some inorganic materials.

Description:

Former beach, highly anthropized its dune area, being totally occupied by buildings and a wall, in front of which it was later necessary to place a rocky coastal defense structure. It has sand only in its bathing area, and a little vestige of sun strip towards the north, where it borders a rocky breakwater that is next to the access channel to Marina Bay.

V. CLIMATE AND HYDRODYNAMIC REGIME

V.1 Wind and wave-generating meteorological factors.

Due to its location, the climate in Antigua and Barbuda is mainly governed by the influence of North Atlantic Subtropical Anticyclone and the easterly winds generated by its southern peripheral circulation, called trade winds.

During winter in the north hemisphere, it can be appreciated certain influence of the southern end of successive troughs, remains of frontal systems that affect the continental territory of North America, the Gulf of Mexico and the Western Caribbean, and the subsequent migratory continental anticyclones, already about to merge with the aforementioned North Atlantic Subtropical Anticyclone. These situations can cause a slight change in the direction of wind and/or incident waves, towards the NE, as well as a certain increase in their respective intensities.

Others factors with incidence on climate are the convergence systems in the anticyclonic flow, such as Tropical Waves, of interest mainly for their rainfall contributions, and because they are a meteorological factor that can give rise to cyclogenesis processes in the Atlantic Ocean.

Local breezes may have some influence on the wind regime, but Antigua's direct exposure to waves generated in the Atlantic Ocean makes them irrelevant when describing the marine climate.

Finally, although less represented in climatology, Tropical Cyclones are of great interest for the energy magnitude of the processes they trigger, including those that take place in the coastal area.

In essence, it is a climate and hydrodynamic regime almost exclusively characterized by the influence of trade winds and waves generated by them, coming from the open ocean, which is occasionally altered by direct impact or distant influence of tropical cyclones, depending on their intensity and path, during the Hurricane Season in the North Atlantic (Fig. 17).

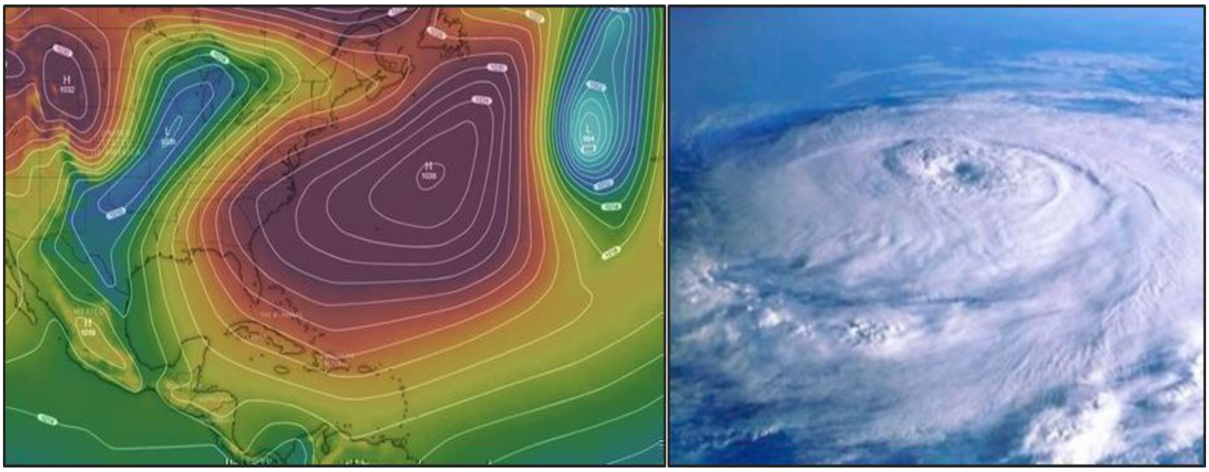


Figure 17: Trade winds, characteristic of the southern peripheral circulation of North Atlantic Subtropical Anticyclone, and winds generated by tropical cyclones are the meteorological factors of greater interest for incident wave generation in the study area.

V.2 Wind Regime.

The analysis of the wind series was done from the data measured at Weather Station 9761115, located on land, on the west coast of Barbuda (See III.4).

The beginning of the series dates back to mid-2011 and its anemometer was disabled in September 2017, in the wake of the powerful Hurricane Irma; therefore, the analyzed information corresponds to the series of the five-year period 2012-2016, which a time minimum that allows a preliminary characterization of wind behavior from the climatological point of view.

The analysis of the wind series allowed verifying the high persistence of east directions (East 41.4%, ENE 21.5% and ESE 16.9 %, accumulating among them 79.8 % of the records), with low to moderate speeds, except during the impact of a tropical cyclone, according to its intensity and path (Figs. 18 and 19).

In addition, the probabilistic analysis of the wind series was carried out by adjusting it to a Gumbel maxima function (Fig. 20). The speed corresponding to 50% of probability during the studied period was 3.93 m/s (14.2 km/h).

Given the predominant directions and speed ranges, wind transport cannot be expected to be determinant in the coastal dynamics of the study area.

On the other hand, the study of the annual cycle also allows verifying that the predominance of east directions, with low to moderate speed, persists throughout the year, although a certain strengthening of trade winds influence is noticeable during the period from April to June (Figs. 21 and 22).

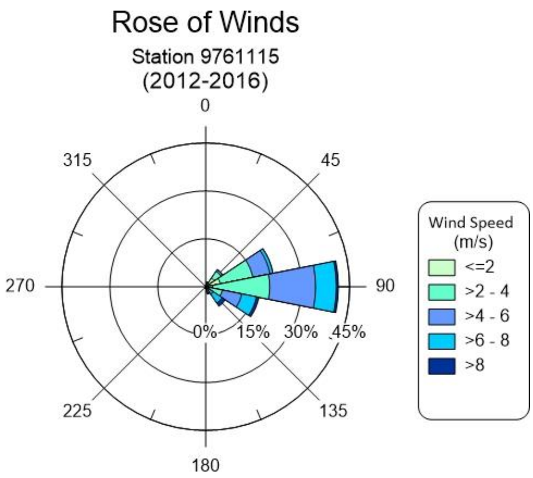


Figure 18: Wind Rose Station 9761115 (2012-2016).

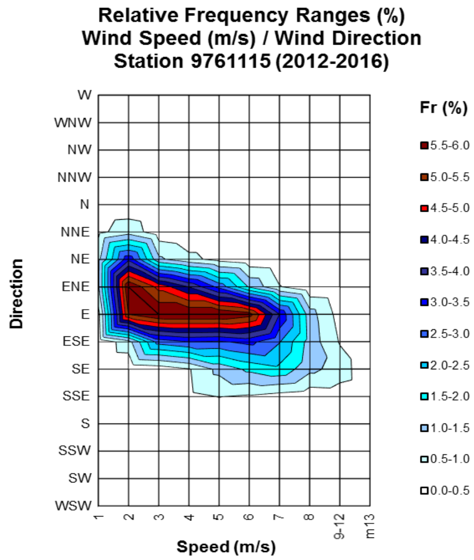


Figure 19: Relative frequency ranges (%): Wind Speed (m/s) vs Direction (2012-2016).

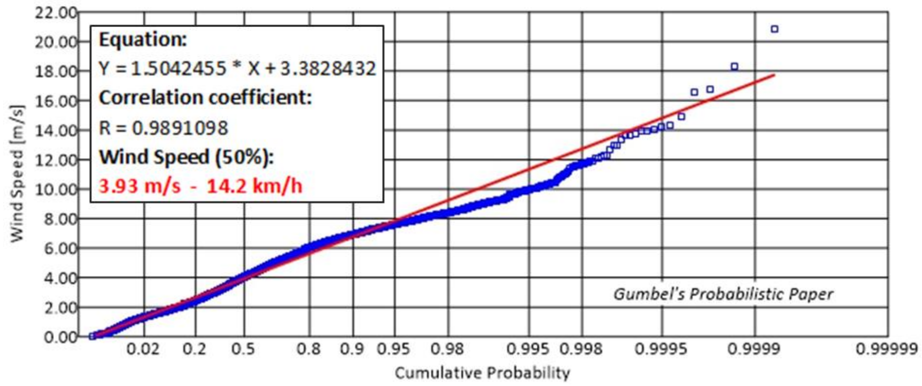


Figure 20: Adjustment of Wind Speed (m/s) series to a Gumbel probabilistic function.

Wind behavior during the daily cycle presents certain influence of local conditions that, at the analyzed station, located in Barbuda, result in greater speeds during the afternoon and components more towards the first quadrant during the night and early morning, and towards the second during the afternoon (Figs. 23 and 24).

Although from this it follows that, while limited, there is some influence of local circulations on the wind regime, the pattern should not be expected to be exactly the same in Runaway Bay Beach, given the location of the station.

In any case, given that the incident wave in Antigua is mainly generated in the Atlantic Ocean open waters, local wind circulations will not be of high interest for the study of incident wave behavior in the study area, as well as in currents and sediment transport induced by them in the coastal area.

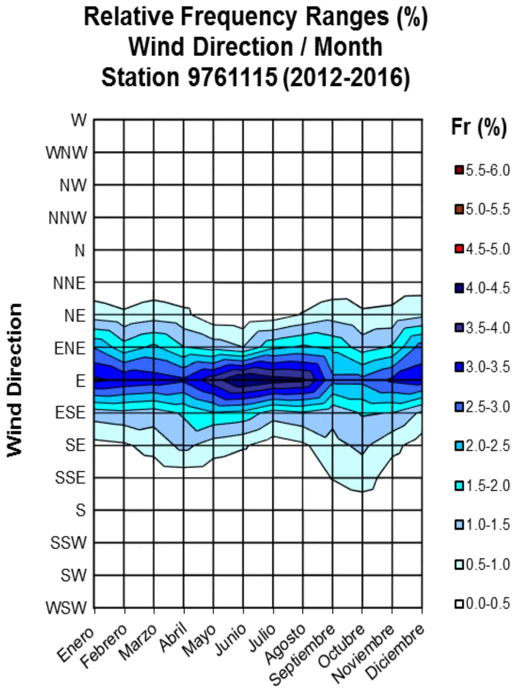


Figure 21: Relative frequency ranges (%): Wind. Direction vs Month. Station 9761115 (2012-2016).

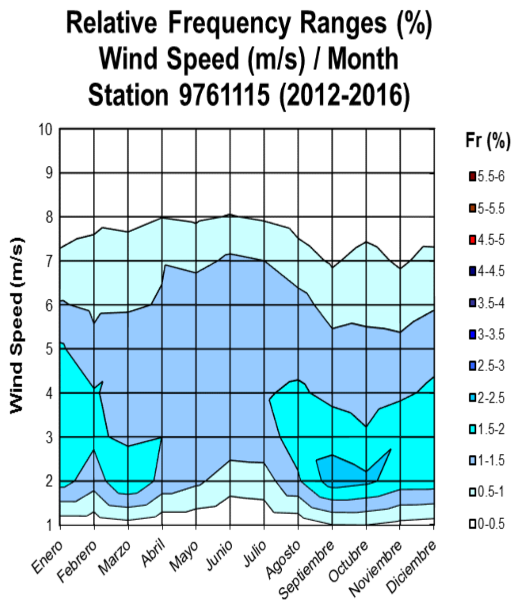


Figure 22: Relative frequency ranges (%): Wind. Speed (m/s) vs Month. Station 9761115 (2012-2016).

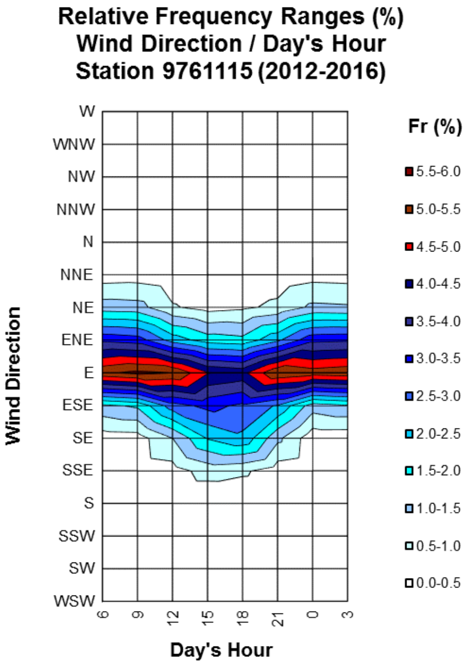


Figure 23: Relative frequency ranges (%): Wind. Direction vs Time of Day. Station 9761115 (2012-2016).

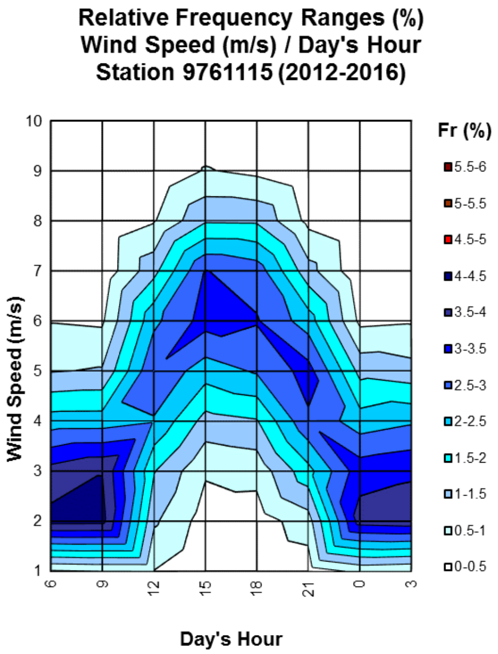


Figure 24: Relative frequency ranges (%): Wind. Speed (m/s) vs Time of Day. Station 9761115 (2012-2016).

V.3 Wave Regime.

The wave series analysis was carried out from the data measured by the Oceanographic Buoy 41040, located in the Atlantic Ocean, about 900 km to the ESE of the study area, having been selected as the most representative of the incident wave in Antigua, among the available options (See III.4).

The beginning of the series dates to mid-2005, though the direction of the dominant wave component was only recorded regularly from mid-2013; therefore, the analyzed information corresponds to the 16-year series 2006-2021, reduced to the period 2014-2021 for the composition of the wave rose.

The analysis of data from the period 2014-2021 allowed verifying the high persistence of east directions (East 39.4%, ENE 19.4% and ESE 12.9%, accumulating among them 71.7% of the records). The 67.6% of the records correspond to Significant Wave Height (Hs) values in the range of 1.0 m to 2.0 m (Fig. 25).

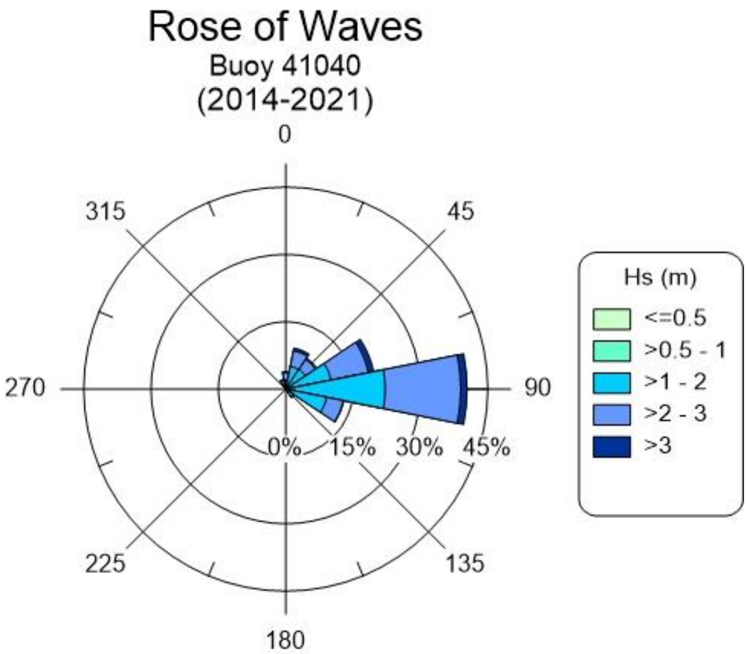


Figure 25: Wave Rose. Oceanographic Buoy 41040 (2014-2021).

The probabilistic analysis of the series of Significant Wave Height (Hs) and Peak Period (Tp), for the period 2006-2021, was carried out through their adjustment to Gumbel maxima function of (Figs. 26 and 27).

The values corresponding to 50% of probability during the studied period (2006-2021) were Hs = 1.91 m and Tp = 8.78 s.

While, the values exceeded only 12 hours a year during the studied period (2006-2021) were Hs_{12} = 4.48 m and Tp_{12} = 18.83 s.

Given the low level of wave energy dissipation in the deep waters of the open ocean, in spite of the distance of more than 900 km between the study area and the oceanographic buoy 41040, these values will be considerate as representative of the Mean Regime of incident wave from deep waters, using numeric modeling to simulate its propagation and transformation to the study area.

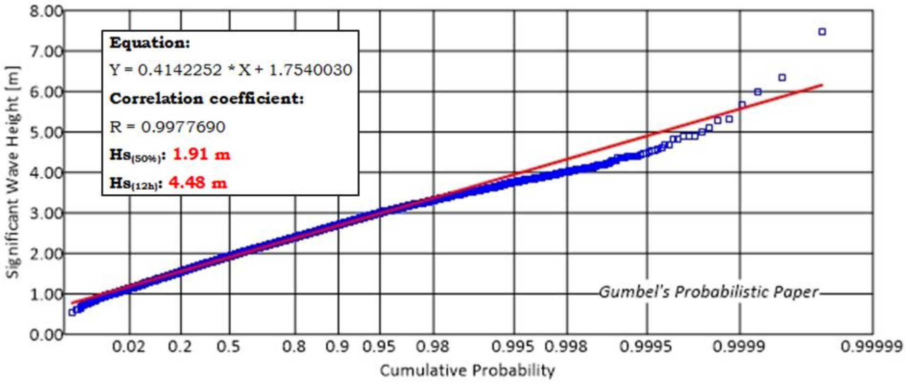


Figure 26: Significant Wave Height (m) adjusted to a Gumbel probabilistic function.

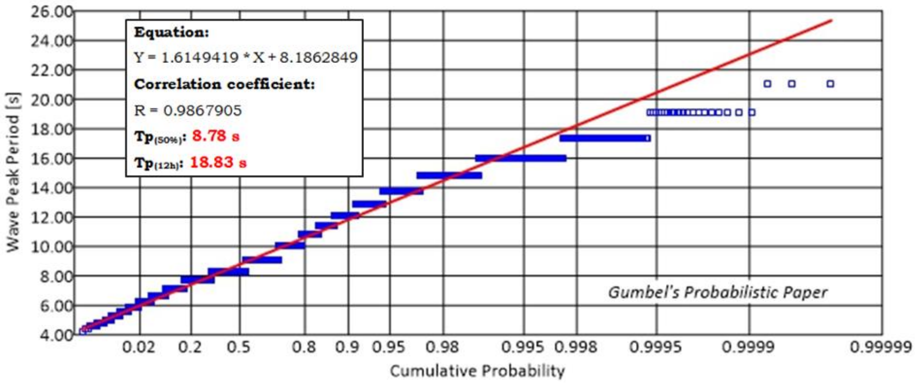


Figure 27: Wave Peak Period (s) adjusted to a Gumbel probabilistic function.

V.4 Tropical Cyclones.

The analysis of the incident wave Extreme Regime was done from of the study of tropical cyclone time series of Atlantic Reanalyze project (NOAA) for the period 1950-2021, applying the methodology referred in section III.4.

During this period, the paths of 74 tropical cyclones (Table 13) crossed by the defined polygon of about 100 nautical miles surrounding the study area, contributing to the series 246 records of maximum sustained winds.

Table 13: Tropical cyclones that probably impacted the study area between 1950 and 2021.

TROPICAL CYCLONES 1950-2021 (15.48°LN - 18.81°LN / 60.12° LW - 63.59° LW)											
Year	**Name**	**Cat**	**Year**	**Name**	**Cat**	**Year**	**Name**	**Cat**	**Year**	**Name**	**Cat**
1950	BAKER	H2	1974	CARMEN	TD	1995	SEBASTIEN	TD	2010	GASTON	TD
1950	DOG	H4	1974	UNNAMED	TD	1996	BERTHA	H1	2011	IRENE	TS
1954	ALICE	H1	1975	ELOISE	TD	1996	HORTENSE	TS	2011	MARÍA	TS
1955	IONE	TS	1979	CLAUDETTE	TS	1997	ERIKA	H1	2011	OPHELIA	TD
1956	BETSY	H2	1979	DAVID	H4	1998	BONNIE	TS	2012	ISAAC	TS
1959	EDITH	TS	1979	FREDERIC	TS	1998	GEORGES	H3	2012	RAFAEL	TS
1960	DONNA	H3	1981	FLOYD	TD	1999	JOSÉ	H2	2014	GONZALO	H1
1961	FRANCES	TS	1981	GERT	TS	1999	LENNY	H3	2015	DANNY	TS
1962	DAISY	TS	1981	UNNAMED	TD	2000	CHRIS	TD	2015	ERIKA	TS
1963	HELENA	TS	1983	UNNAMED	TD	2000	DEBBY	H1	2017	IRMA	H5
1964	CLEO	H4	1984	ARTHUR	TD	2000	HELENE	TD	2017	JOSÉ	H4
1965	BETSY	TS	1987	UNNAMED	TD	2004	JEANNE	TS	2017	MARÍA	H5
1966	FAITH	TS	1988	CHRIS	TD	2006	CHRIS	TS	2018	BERYL	TS
1966	INEZ	H3	1989	DEAN	H1	2007	INGRID	TD	2019	DORIAN	TS
1969	UNNAMED	TD	1989	HUGO	H4	2007	NOEL	TD	2020	LAURA	TS
1969	ANNA	TS	1990	KLAUS	H1	2007	OLGA	TS	2021	FRED	TD
1969	INGA	TD	1995	IRIS	TS	2009	ERIKA	TS	2021	GRACE	TD
1971	DORIA	TD	1995	LUIS	H4	2010	EARL	H3			
1973	CHRISTINE	TS	1995	MARILYN	H1	2010	FIONA	TS			

The probabilistic analysis of the maximum sustained wind series was carried out by adjusting it to a Gumbel maxima function (Fig. 28).

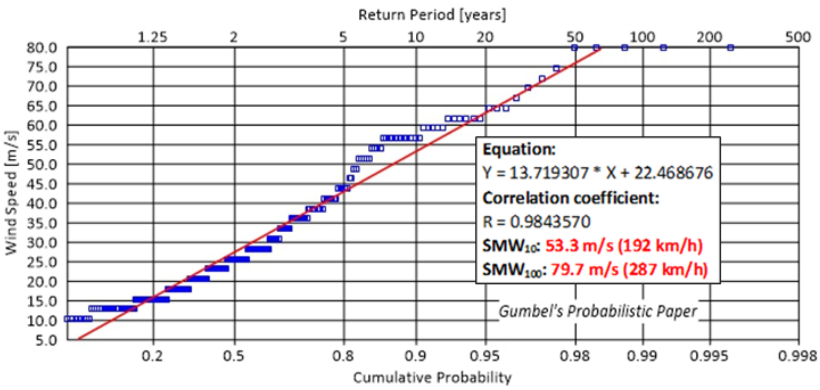


Figure 28: Maximum sustained winds (m/s) series adjusted to a Gumbel probabilistic function.

The values corresponding to return periods of 10 and 100 years for the analyzed series (1950-2021) were SWS_{10} = 192 km/h and SWS_{100} = 287 km/h.

Likewise, the return periods corresponding to the different hurricane categories defined on the Saffir-Simpson scale (Table 14) were obtained. These values are shown as relevant information, although those corresponding to return periods of 10 and 100 years will be the ones used for the parameterization of the situations to simulate.

Table 14: Return Period of the impact of a Tropical Cyclone on Antigua according to its intensity.

Classification	SMW Range	Ac. Prob	Tr
Tropical Storm	63 - 118 km/h	0.2378	1-2 Years
Hurricane Cat 1	119 - 153 km/h	0.6299	2-3 Years
Hurricane Cat 2	154 - 177 km/h	0.7965	4-5 Years
Hurricane Cat 3	178 - 209 km/h	0.8694	7-8 Years
Hurricane Cat 4	210 - 250 km/h	0.9294	14 Years
Hurricane Cat 5	251 - - km/h	0.9686	32 Years

V.5 Definition of Situations to Simulate.

According to the abovementioned results, the situations to simulate were defined, to obtain a quantitative and graphic description of the behavior of the incident wave in Runaway Bay Beach, the coastal currents induced by the waves, and the coastal sediment transport generated in turn by these currents.

The design of the simulations faced the difficulty of dealing with a beach sheltered from the waves coming from the characteristic directions of the usual wave regime in deep waters. This does not mean that such directions do not have incidence in the beach's processes, but that the wave reaches the beach after going through various transformation processes that must be considered by the model to use.

Of particular interest are the dissipation of wave energy by friction with the seabed, refraction that modifies the advance direction of the wave front in search of the perpendicular to the isobaths, and the diffraction when hitting rocky ledges, rocky lows areas or reefs, or patched rocky outcrops, which results in the spread of radial waves around the point of diffraction.

Values corresponding to estimated wave were entered into the grid for indefinite depths that, in any case, would lead to an overestimation of the final results, which was considered preferable.

Grids that cover an extensive area of propagation to the beach were used, thus allowing the model to stabilize its results (See III.5.2).

With all the above-mentioned considerations, and also taking into account the shoreline orientation and possible directions with incidence in the coastal dynamics of the beach, the following situations to simulate were defined:

- Mean Regime (NNE Direction): Equivalent to 50% of accumulated probability, resulting from adjustment to a Gumbel maxima probabilistic function, of Significant Wave Height (Hs) and Wave Peak Period (Pp) Series, according to records of oceanographic buoy 41040.
- Event of the Year (NNE Direction): Value of Hs with probability to be exceeded only 12 hours a year. No correspondence was observed with the Pp exceeded only 12 hours a year; therefore, for this case, it was also used the Pp corresponding to 50% of accumulated probability.
- Hurricane Category 3 (SWS=192 km/h) (NNE, N, NW, W and SW Directions): Event with a Return Period equivalent to 10 years, obtained from the probabilistic adjustment to a Gumbel maxima function, from the series of estimated Maximum Sustained Winds or measured for a tropical cyclone, during its passage through the defined polygon, framed in the surroundings of 100 nautical miles of distance to the study area.
- Hurricane Category 5 (SWS=287 km/h) (NNE, N, NW, W and SW Direction): Event with a Return Period equivalent to 100 years, obtained through a similar procedure from the same series.

By applying the methodology proposed by Sverdrup, Munk and Bretsclineider, referred in the Shore Protection Manual (1984) and described in section III.4.3, it was calculated the wave height generated by a hurricane with the denoted intensity, and incident in deep waters. It was considered the wave height with regard to the possible paths conditioning the defined directions to simulate.

The selection of MoPLA model of the Coastal Modeling System, developed by the University of Cantabria (see section III.4), responded to its capacity to simulate the aforementioned processes. The parameters introduced in each situation to be simulated are shown in Table 15.

Table 15: Situations to simulate. Data input of wave values in waters of indefinite depth.

Wave Data Input to Mopla 2.0											
Events	**Direction**	**Duration**	**Hs (m)**	**Tp (seg)**	**Peak Fr**	**Fr Max**	**GAMA**	**Comp fr**	**Comp Dir**	**Tide Width (m)**	**Dispersion**
Mean Regime	*NNE*	12 hours	1.91	8.78	0.11	0.25	3.30	16.00	15.00	0.30	16.00
Event of Year	*NNE*	12 hours	4.48	8.78	0.11	0.25	3.30	12.00	11.00	0.30	12.00
TC (Tr 10 Years)	*N y NW*	12 hours	5.71	9.23	0.11	0.25	3.30	12.00	11.00	0.30	12.00
TC (Tr 100 Years)	*N y NW*	12 hours	8.51	11.26	0.09	0.20	5.00	10.00	9.00	0.30	10.00
TC (Tr 10 Years)	*W y SW*	12 hours	8.57	11.30	0.09	0.20	3.30	10.00	9.00	0.30	10.00
TC (Tr 100 Years)	*W y SW*	12 hours	12.76	13.79	0.07	0.17	5.00	8.00	7.00	0.30	8.00

V.6 Mean Regime.

V.6.1 Wave Simulations.

The Mean Regime responds only to incident wave from NNE on the chained grids designed for this purpose.

In practice, the Mean Regime results from waves that are developed under the influence of trade winds in Atlantic Ocean waters, and have an incidence on Antigua and Barbuda island shelf coming from of east.

In their transit on the shelf, to the north of Antigua, these waves undergo important transformations as a result of the friction with the seabed, and processes of wave refraction, diffraction, and even reflection. Once they arrive at the NW end of Antigua, the refraction and diffraction favor a turn that makes the waves to approach from NNE directions, on the chained grid.

Wave transformation continues in a similar way until making the waves to affect the breaking zone coming from NW, after dissipating a good part of their initial energy, with heights of less than 1.0 m, being even lower at the northern end of the beach, sheltered by shoals and rocky outcrops (Fig. 29).

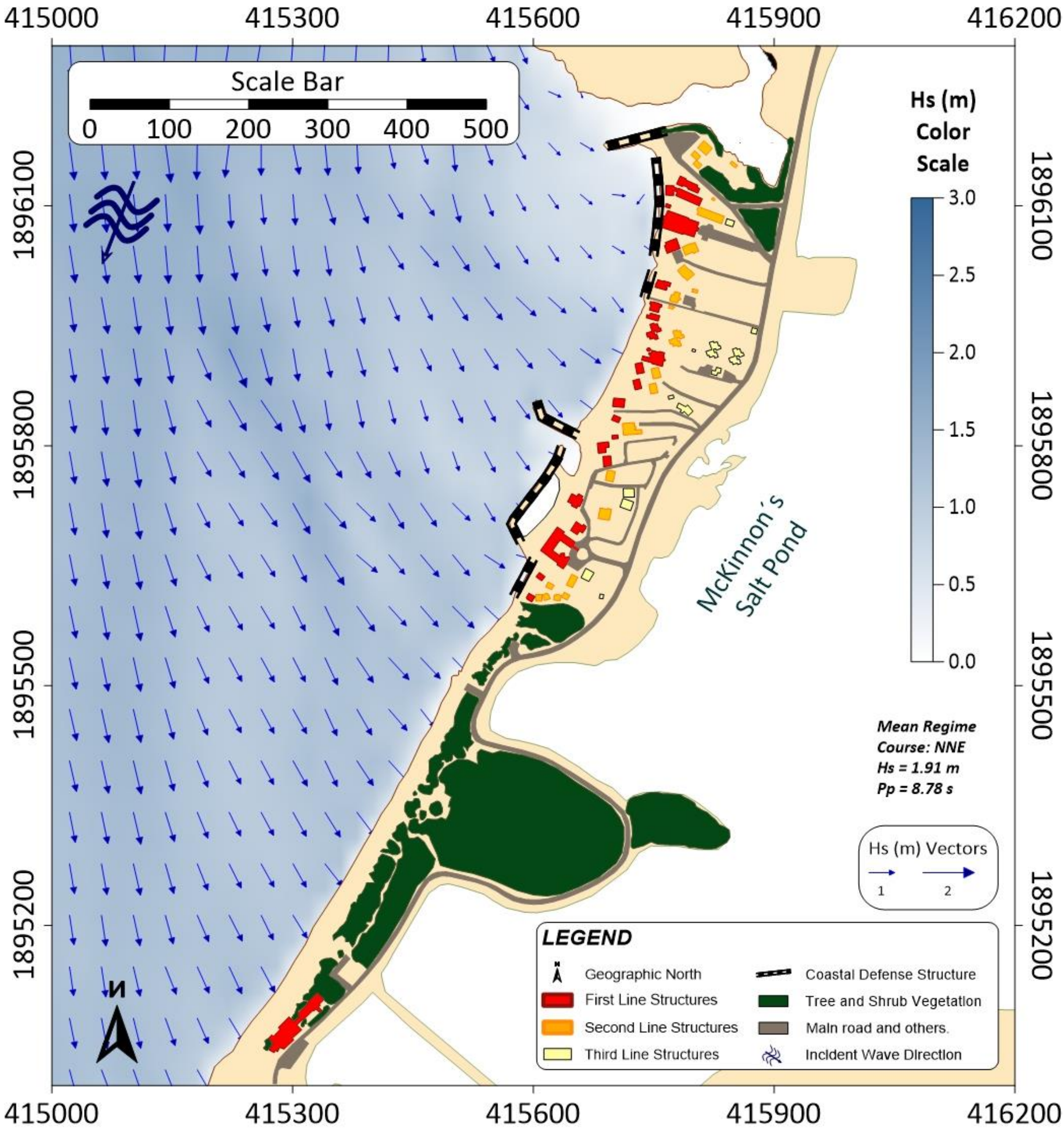


Figure 29: Mean Regime (NNE). Wave Height Vectors.

V.6.2 Coastal Currents.

The graphic representation of the results obtained in the numeric modeling of coastal currents, are shown in Figure 30.

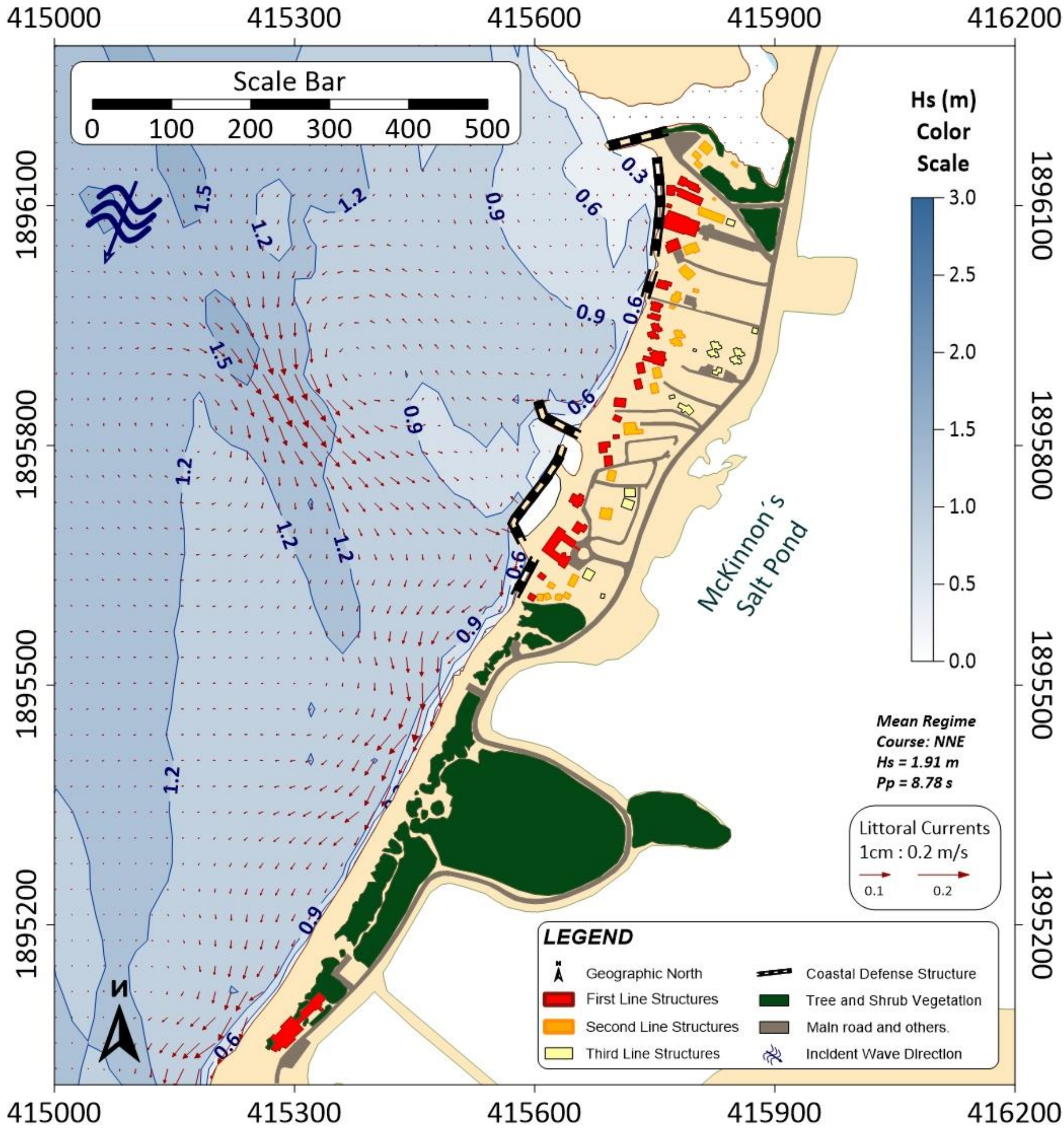


Figure 30: Mean Regime (NNE). Currents and Wave Height Contours Vectors.

The slightly oblique incidence of waves on the beach generates a well-defined long-shore drift in the entire Sector 1 (to the south of the breakwaters), with currents of short intensity from NE to SW, which persist for almost the entire year, with variations in their magnitude.

The reflection of the incident wave on the breakwater generates rip currents that, if increased when facing the impact of extreme events, could undermine the structure in case it was not properly located.

The low energy of the incident waves in sectors 3 and 4 (north of the breakwaters), very sheltered from these directions by shoals and rocky outcrops, results in the almost null development of coastal currents.

These results coincide with the field observations, where it was not noticed that the central pier was interrupting the coastal transport significantly; while, the evidence of erosion was remarkable immediately to the south of the breakwaters, and of accretion on the southern end of the beach.

V.6.3 Sediment Transport.

Figure 31 shows a graphic representation of EROS model output, which attempts to estimate quantitatively the magnitude of sediment transport by coastal currents and the seabed surface variations.

In correspondence with the results obtained for wave and coastal currents, it is perceived more active coastal dynamics in Sector 1 of the beach. The coastal sediment transport takes place there from NE to SW, primarily, without being very representative at present; although it marks a noticeable trend as a result of the persistence of this situation during almost all year round, with moments of higher or lower intensity.

Likewise, the yellow line shows that, at a certain moment, this regime is able to displace sand towards the submerged bar, strengthening it, so that the it becomes another element for dissipating incident wave energy.

These results must be analyzed keeping in mind that the model assumes that all the seabed is composed of sediments susceptible to be transported, when in fact in this site there are shoals and rocky outcrops, like the one found in front of the coastal defense structures in the central part of the beach, where the model estimates seabed variations that are impossible in practice.

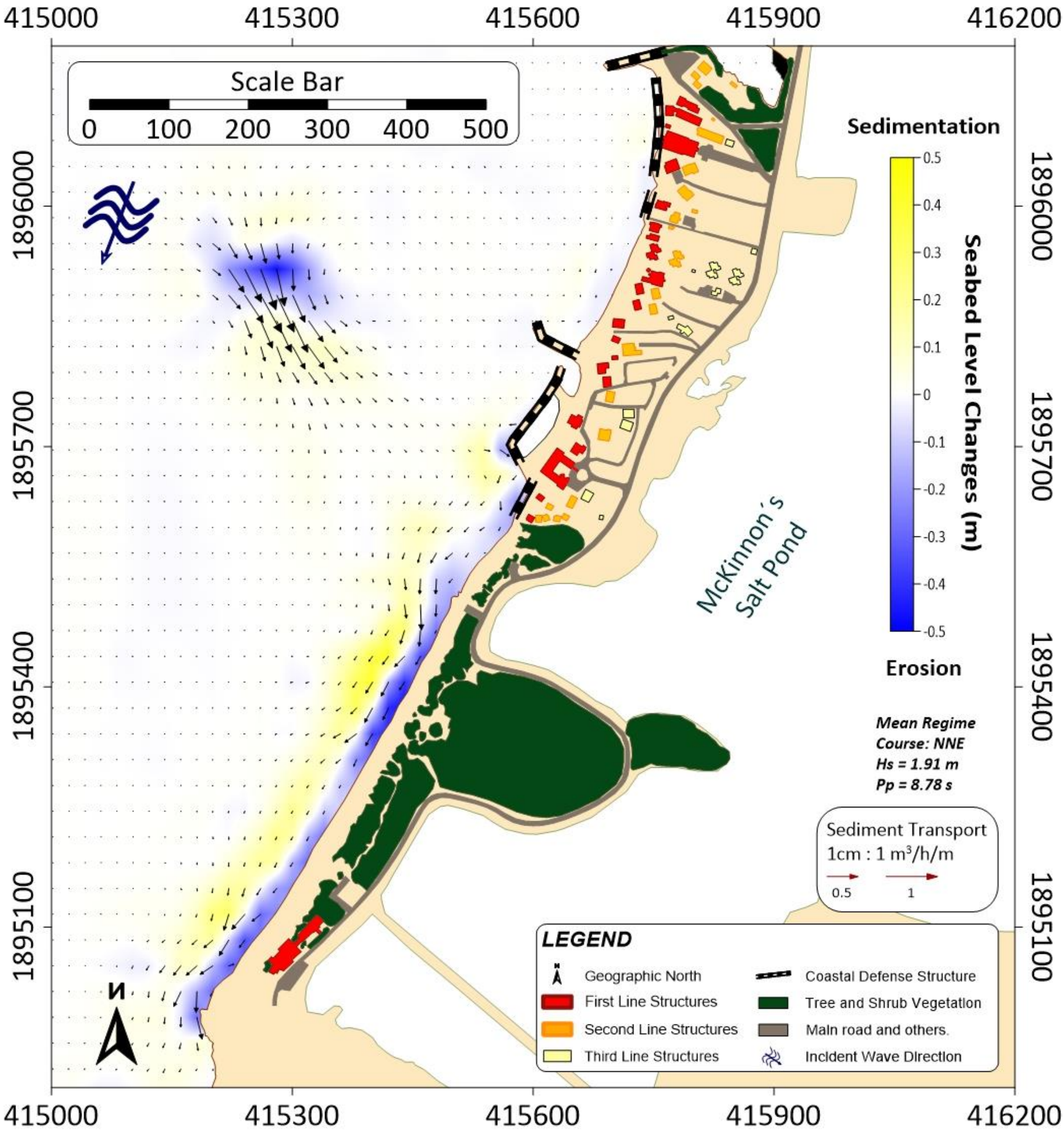


Figure 31: Mean Regime (NNE). Transport and Seabed Variation Contours Vectors.

V.7 Extreme Regime.

As has been noted, in the study area, there is a very high persistence of the usual wave regime. It is only altered in moments of greater intensity of the trade winds and the passage of tropical cyclones.

For this reason, simulations were carried out corresponding to the event with probability of being exceeded only 12 hours a year, assuming similar direction to the predominant one during almost all year round (NNE in the grid); and for the passage of tropical cyclones with return periods of 10 and 100 years for N, NW, W and SW directions.

As an example, this section will show results corresponding to the simulation of the impact of a tropical cyclone with a 10 year return period, according to its intensity, for NW, W and SW directions.

The results of the outputs corresponding to each simulated event and direction are shown in Annexes III and IV.

V.7.1 Wave Simulation.

According to their paths, tropical cyclones can cause wave to affect the study area, from various directions between NNE and SW.

Being the maximum winds radius of a tropical cyclone, as a general rule, lower in its western sector, this will determine the maximum wave height. Given the geographic location and shoreline orientation of Runaway Bay Beach, it is assumed that the N and NW directions are generated in the western sector of tropical cyclones whose paths cross over the north of Antigua, so that wave height is lower. On the contrary, it is assumed that the W and SW directions are generated in the eastern sector of tropical cyclones whose paths pass through the south of Antigua in a SE-NW direction, so that wave height is higher.

The results obtained from the simulation of the case of a Tropical Cyclone with Return Period equivalent to 10 years, for the NW, W and SW incident directions in the grid, are shown in Figures 32, 33 and 34.

It is noteworthy that the different obstacles and the soft profile slope are able to dissipate a large part of the incident wave energy, even for the case of directions more perpendicular to the shoreline orientation.

The wave arrives with greater energy at the central and south area of the beach. While in Sector 1 it reaches heights of up to 1.8 m in the breaking zone, in the north part it barely exceeds 1.2 m.

The direction undergoes certain variations due to refraction and diffraction processes, the latter, particularly remarkable, as a result of the interaction of the waves with the rocky shoal in the central area.

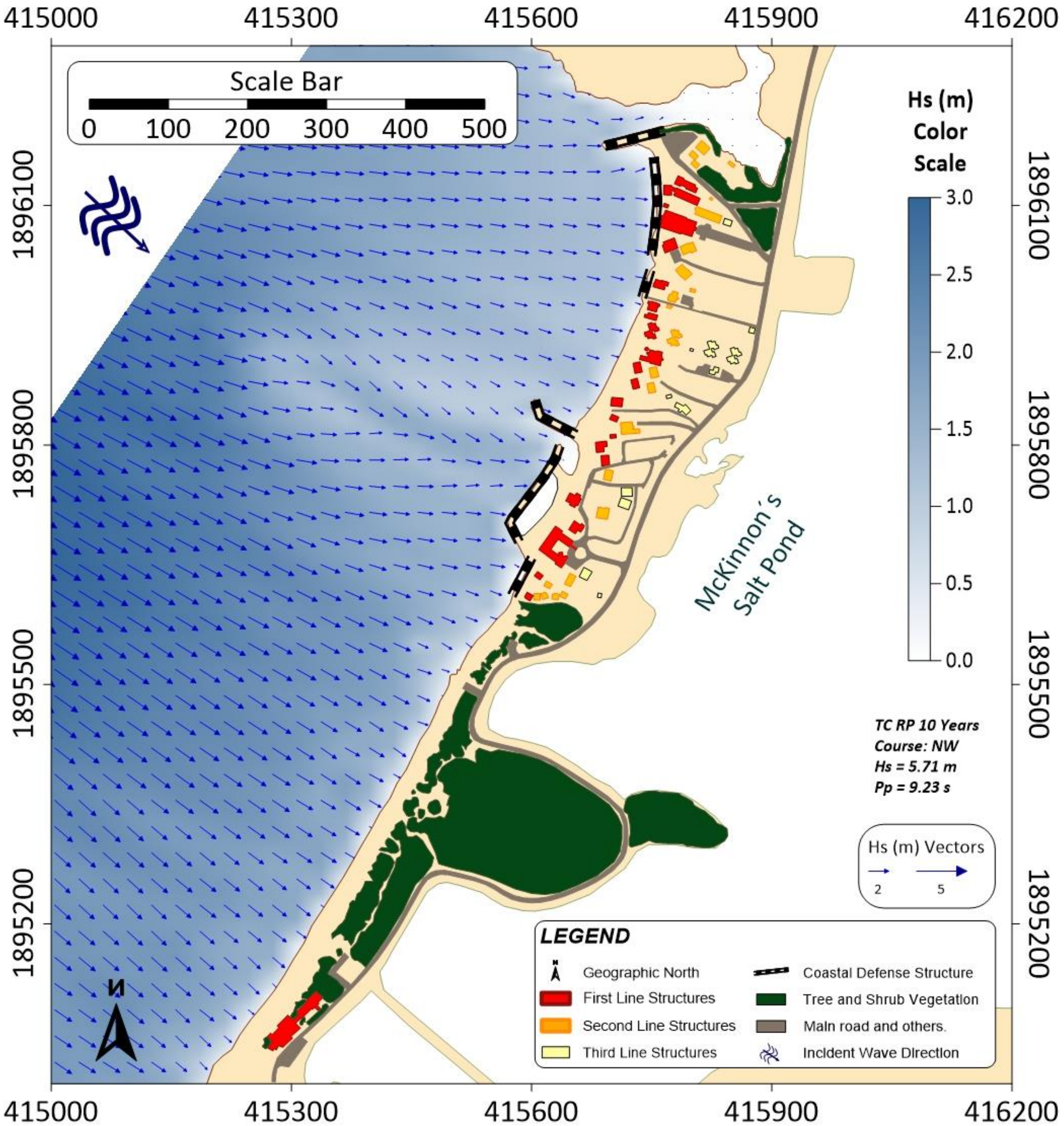


Figure 32: Tropical Cyclone (NW. Tr: 10 Years). Wave Height Vectors.

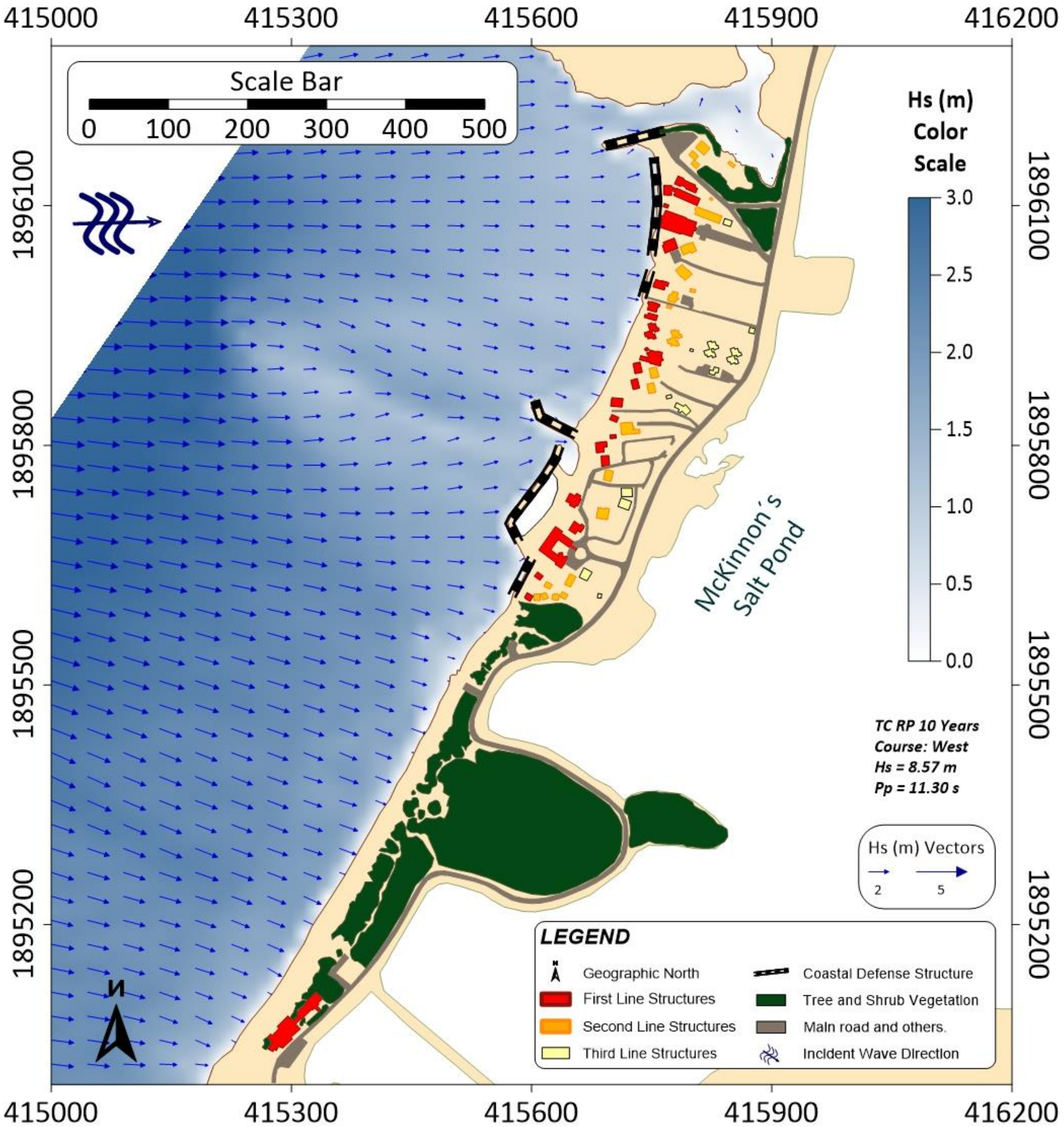


Figure 33: Tropical Cyclone (W. Tr: 10 Years). Wave Height Vectors.

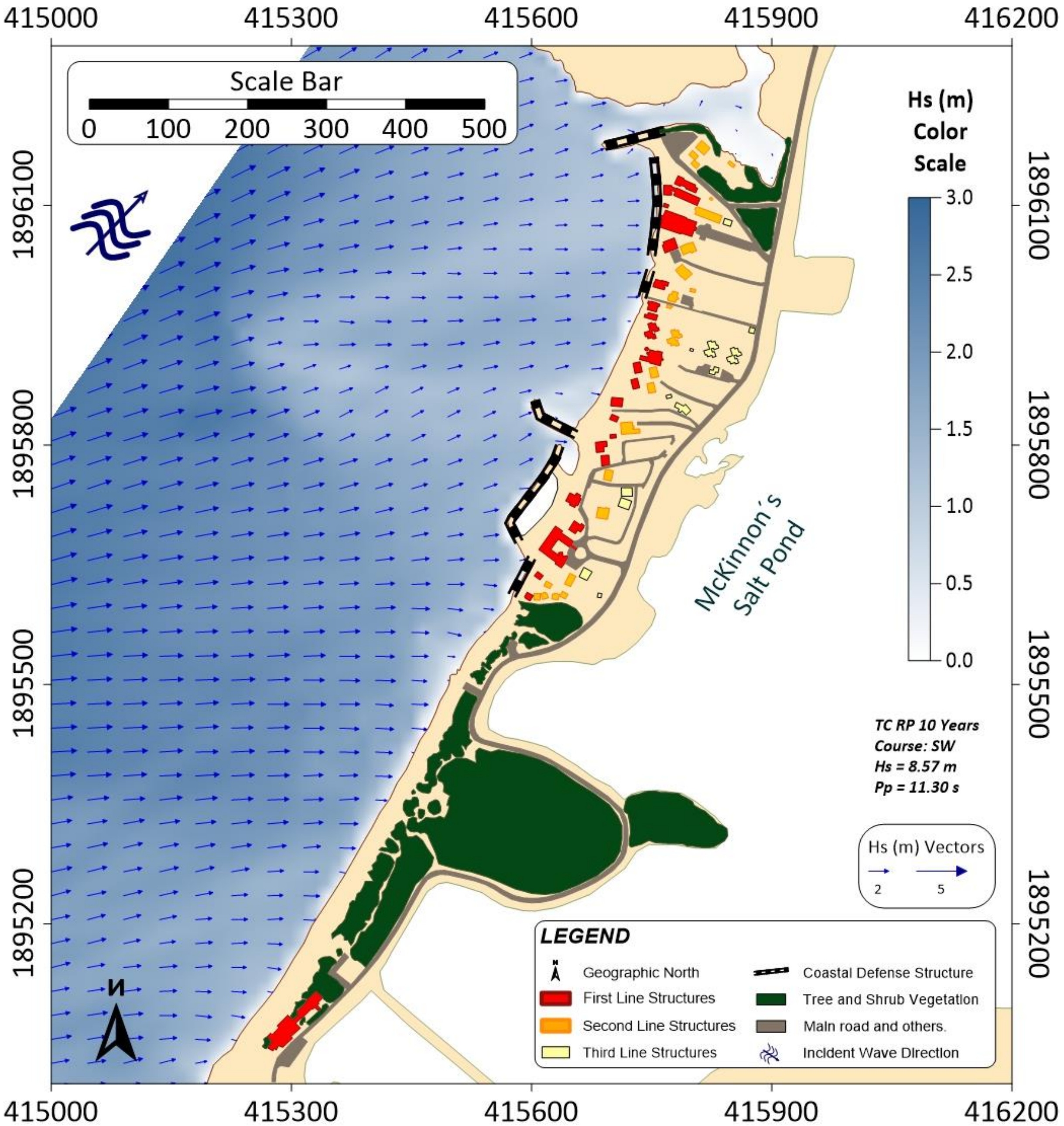


Figure 34: Tropical Cyclone (SW. Tr: 10 Years). Wave Height Vectors.

V.7.2 Coastal Currents.

The graphic representations of the results obtained in the numeric modeling of the coastal currents for the simulated directions, are shown in Figures 35, 36 and 37.

The model outputs indicate that the more perpendicular incidence from these directions, and greater wave energy, favor the formation of circulation cells with rip currents, particularly noticeable for all directions, in the north end of Sector 1 (immediately south of the breakwaters in the central area). The SW direction enables the reverse longshore drift, while it also favors the appearance of rip currents in the north end of the beach (Sector 4). It is known that this type of currents, in case of higher energy events such as those simulated, can occur with greater intensity in areas surrounding rocky structures perpendicular to the shoreline.

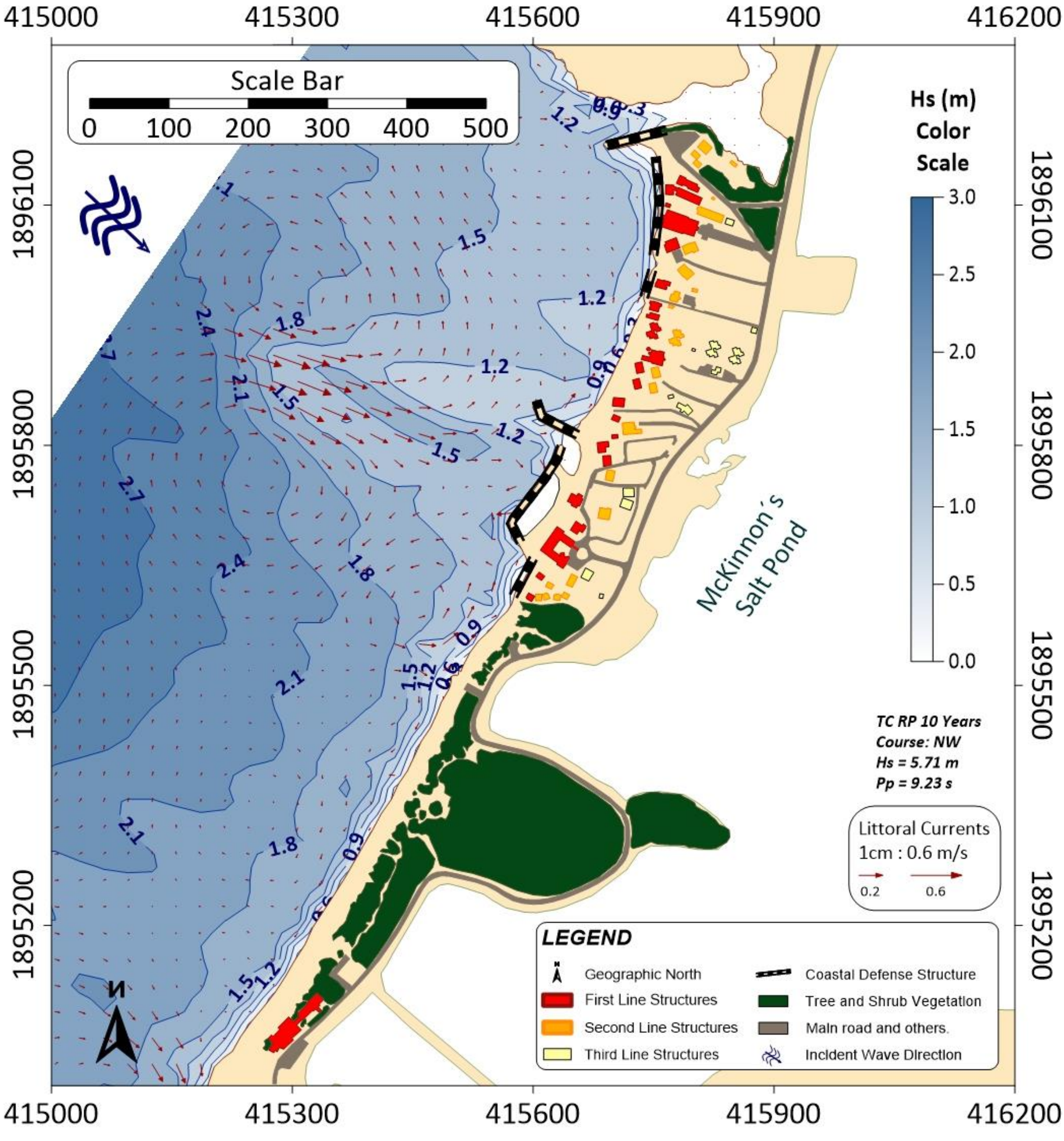


Figure 35: Tropical Cyclone (NW. Tr: 10 Years). Currents and Wave Height Contours Vectors.

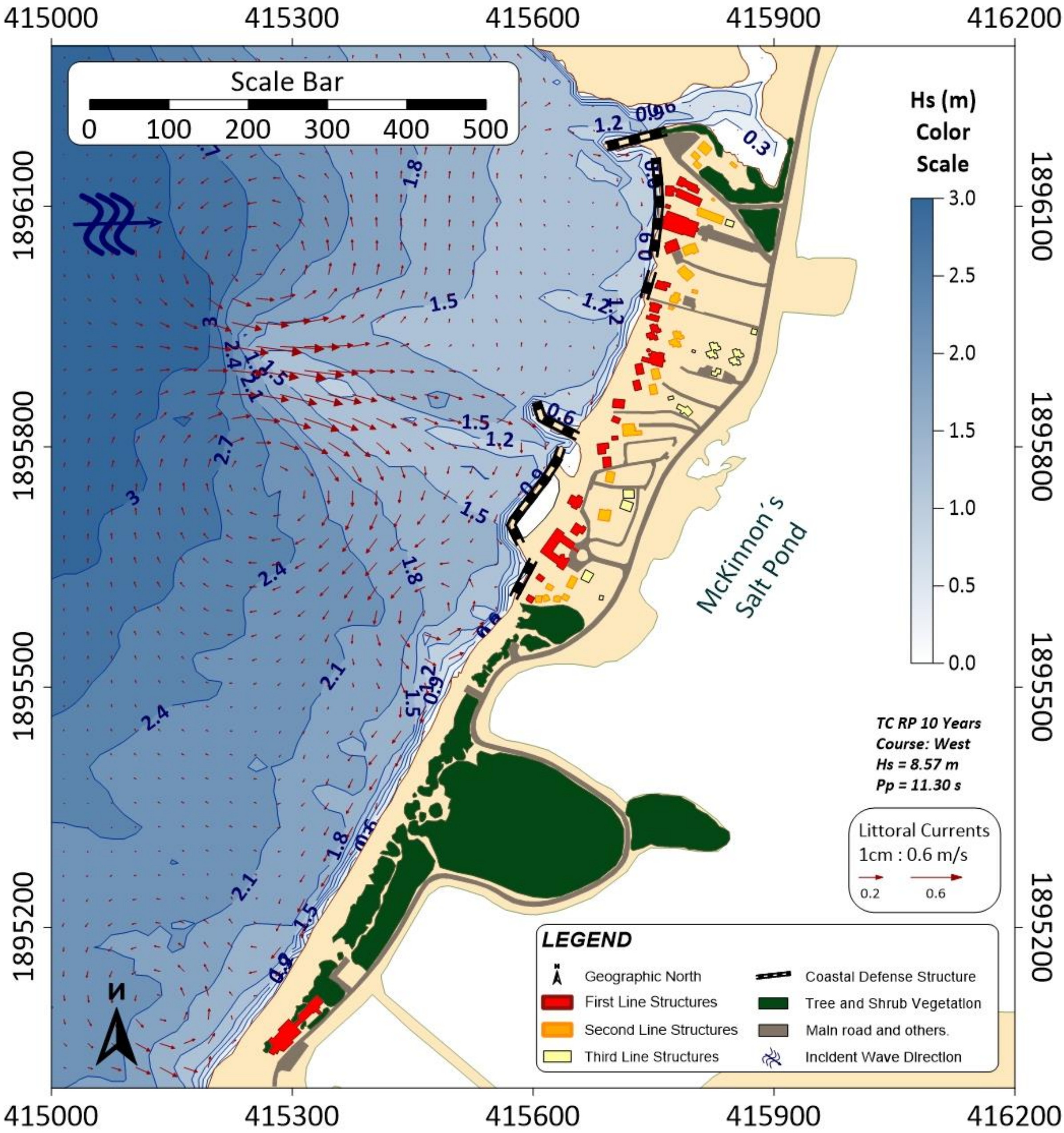


Figure 36: Tropical Cyclone (W. Tr: 10 Years). Currents and Wave Height Contours Vectors.

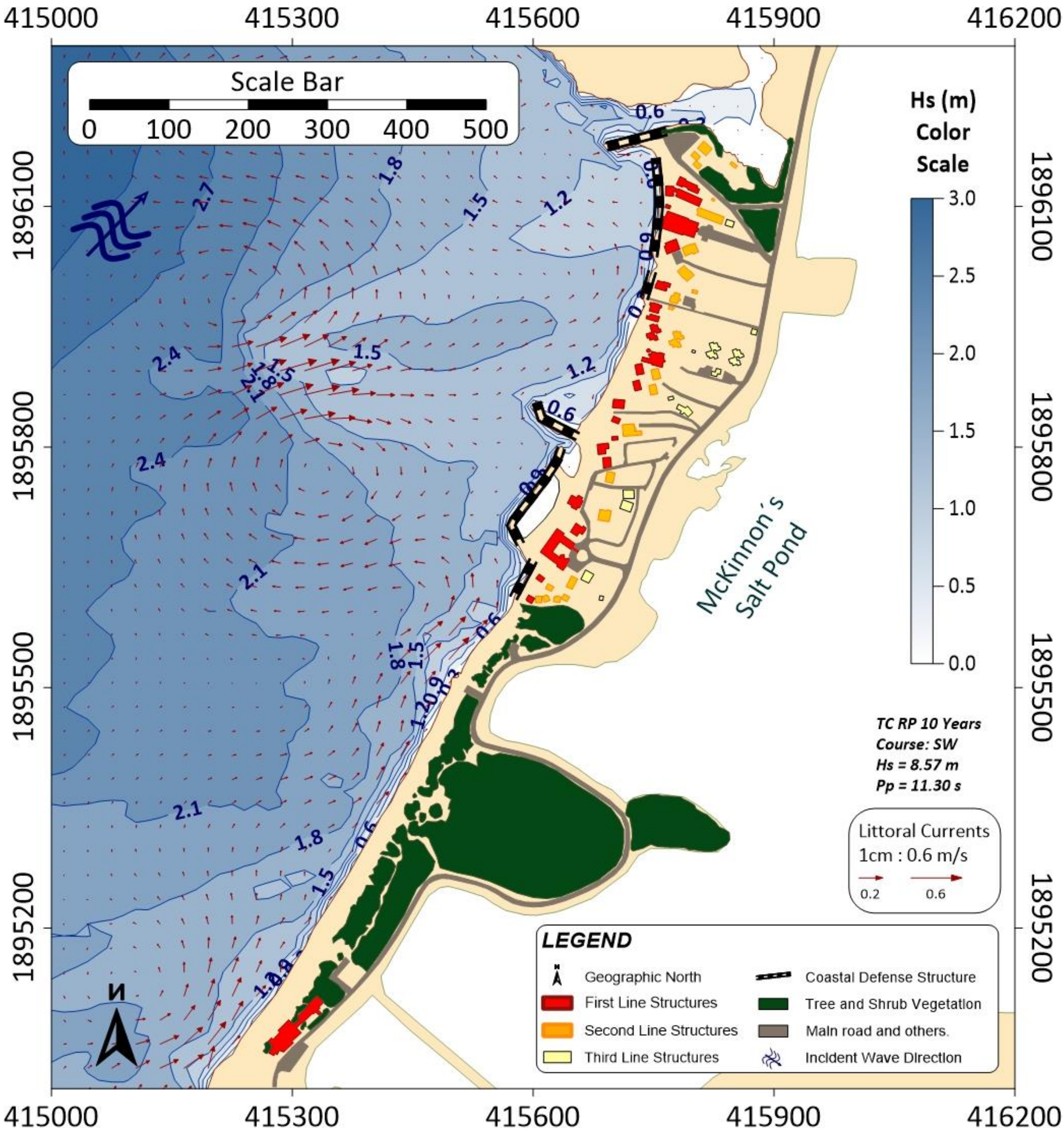


Figure 37: Tropical Cyclone (SW. Tr: 10 Years). Currents and Wave Height Contours Vectors.

V.7.3 Sediment Transport.

Figures 38, 39 and 40 show a graphic representation of EROS model output, which attempts to estimate quantitatively the magnitude of sediment transport by coastal currents and the variations in the seabed surface.

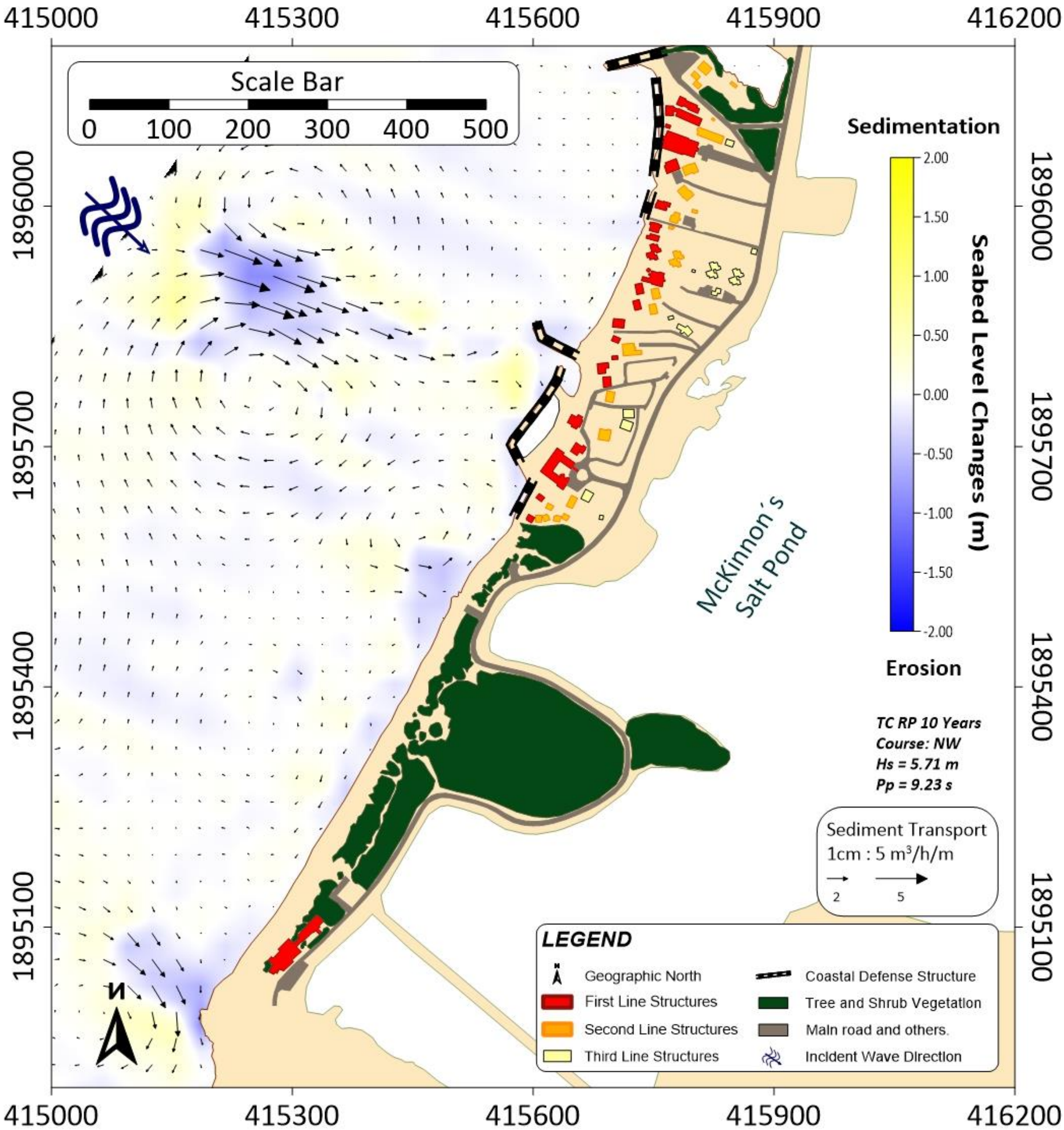


Figure 38: Tropical Cyclone (NW. Tr: 10 Years). Transport and Seabed Variation Contour Vectors.

In correspondence with the results obtained for wave and the coastal currents in the simulated cases for extreme wave, it is similarly observed more active coastal dynamics in Sector 1 of the beach, where the submerged sand bars are strengthened; while offshore transport occurs due to the rip currents in some sectors, and also to the SW at the southwestern end of the beach.

The direction of coastal transport depends on the incident direction and the coastal currents that result from it, being NE to SW for the directions from west and the fourth quadrant, and reverse for the SW direction.

These results should be analyzed keeping in mind the low representation of these events in the climatology of area, and the fact that the model assumes that all the seabed is composed of sediments that can be transported.

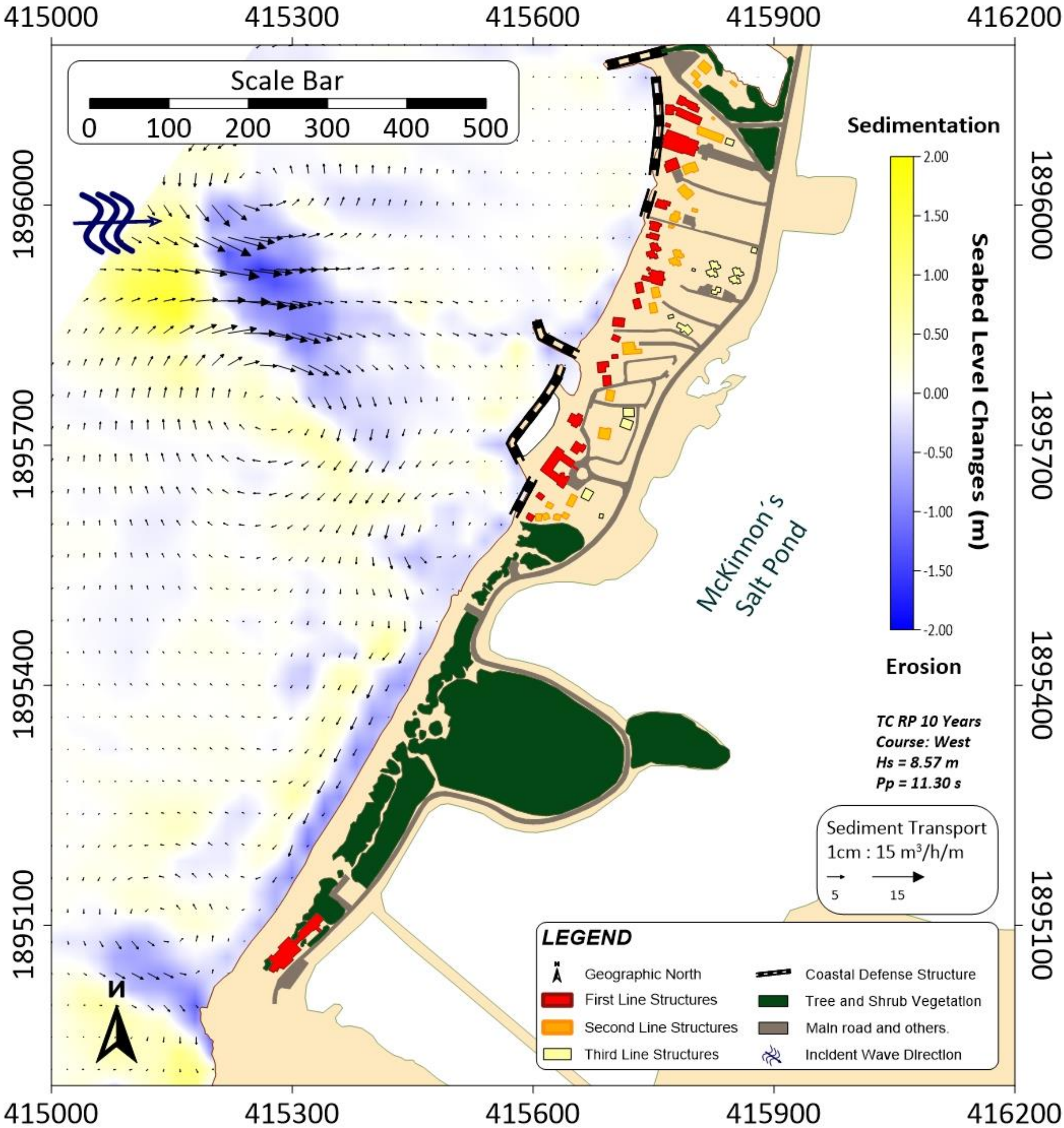


Figure 39: Tropical Cyclone (W. Tr: 10 Years). Transport and Seabed Variation Contour Vectors.

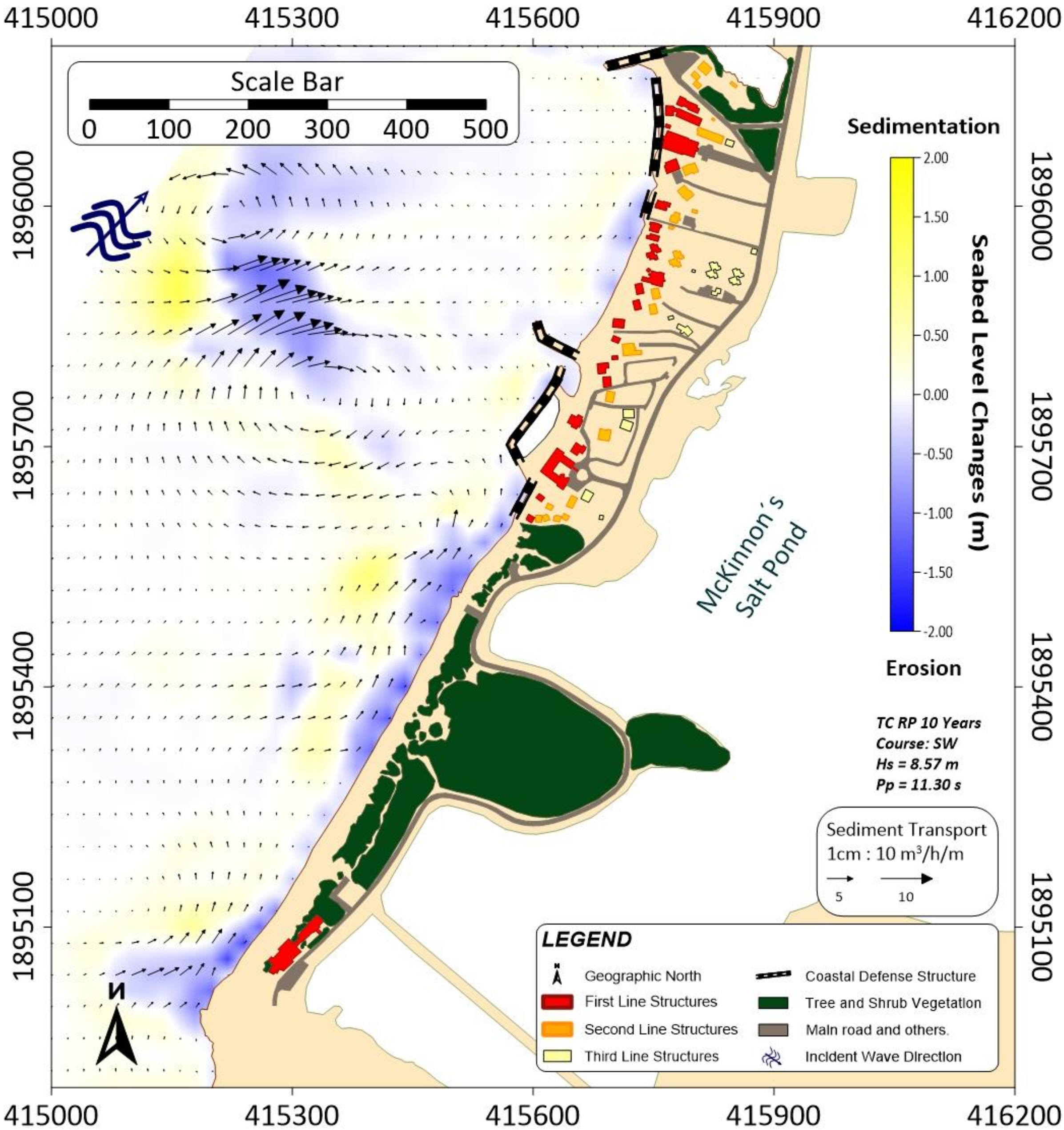


Figure 40: Tropical Cyclone (SW. Tr: 10 Years). Transport and Seabed Variation Contour Vectors.

V.8 Climate Change as a cause of erosion processes.

Since 1990, successive reports of the Intergovernmental Panel on Climate Change (IPCC) have gathered significant results of research carried out on climate change, its evidence, origin, evolution, forecast and implications.

Climate change would be induced by the increase in mean temperature on the Earth's surface, a process called global warming, which has its origin in the over-dimensioning of greenhouse effect as a result of greenhouse gas emissions due to industrial activity, transportation, among others sources.

In turn, this process implies a mean sea level rise, resulting from the thermal expansion of water, and the melting of glaciers. In fact, the directly or indirectly measured increase in mean surface temperature and mean sea level rise, as well as the decrease in the surface occupied by glaciers, constitute three examples of the clearer evidence of change climate advance.

In its VI Report (2022), the IPCC states that: "Global mean sea level rise rate was 1.35 mm per year (0.78-1.92 mm per year, very likely range) during the period 1901-1990, faster than during any other century in at least 3000 years (high confidence). Mean sea level rise has accelerated to 3.25 mm per year (2.88-3.61 mm per year, very likely range) during 1993-2018 (high confidence)."

Long term forecasts indicate a gradual acceleration of mean sea level rise in coming years, reaching around 15 cm to 25 cm by 2050, and 40 cm to 75 cm by 2100, according to the projected scenario, compared to 2020 (Fig. 41).

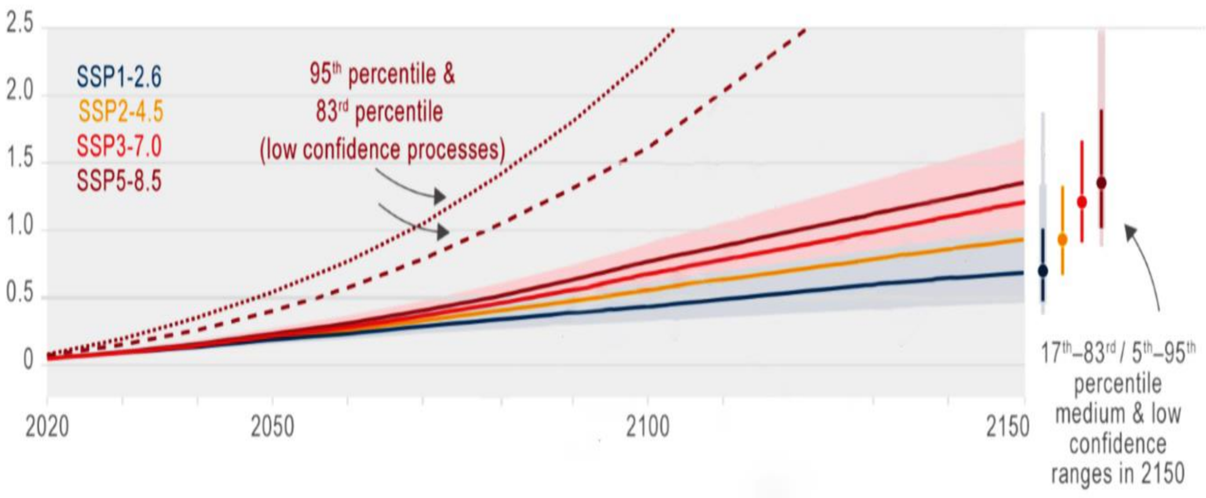


Figure 41: Projected mean sea level rise for four scenarios until 2150 (IPCC, 2022).

The VI Report of the IPCC also relates the increase in coastal erosion, particularly in sheltered coasts, as evidence of the first impacts of change climate-induced mean sea level rise. These processes are also studied from beach morphodynamics: the models by Bruun (1962), and Dean and Maurmeyer (1983) connect sea level rise to shoreline retreat in beaches.

Bruun's Rule establishes a direct relationship between the shoreline retreat (R) in a beach profile and mean sea level rise (S), which in turn will depend on berm height (B), closure depth (h*) and profile length (L) (Fig. 42).

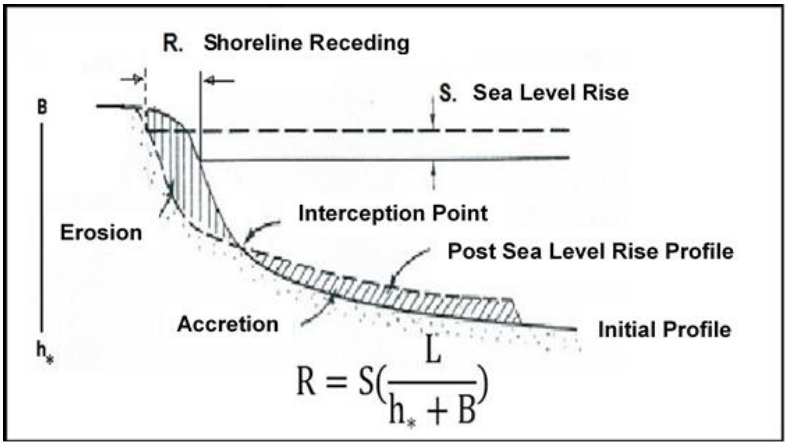


Figure 42: Bruun's Rule (1962).

Dean and Maurmeyer (1983) proposed a model with similar implications, based on the study of barrier islands. These authors foresee that sea level rise will favor the transfer of sand towards the backdune, as part of a profile reconfiguration process that also starts from a direct relationship between mean sea level rise and shoreline retreat, depending on the total length of the profile (addition of submerged profile to closure depth (Lo), emerged profile (W), and backdune profile (LL) to the maximum advance of sand landwards), and the closure depths in the sea (h*) and the coastal lagoon (hL) (Fig. 43).

$$R = S\frac{(L_0 + W + L_L)}{(h_* - h_L)}$$

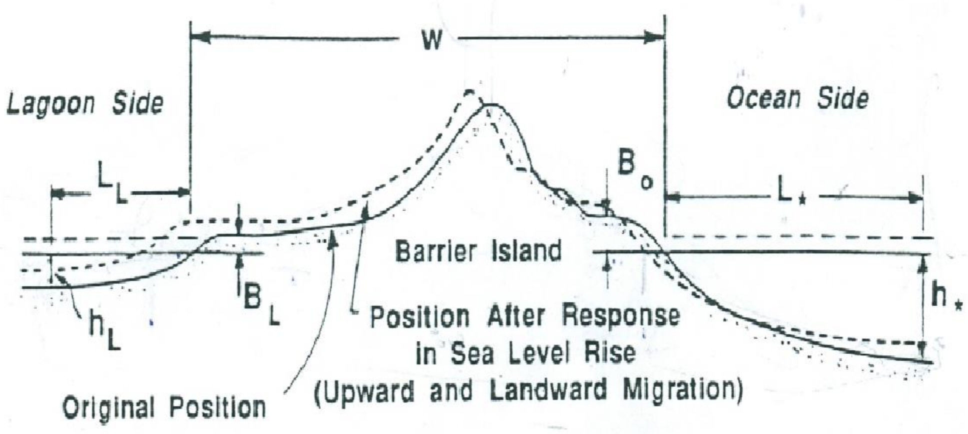


Figure 43: Response of the equilibrium profile in bar islands (Dean and Maurmeyer, 1983).

The projected mean sea level rise leads to anticipate the increase and acceleration of erosion processes in beaches in the medium and long term, so that their management must also foresee the monitoring of their morphodynamic evolution and the conception of strategies that allow to act proactively, depending on the scenario that occurs.

V.9 Summary of results and dynamic functioning.

Runaway Bay Beach is located on the west coast of Antigua, its beach front is oriented from NNW to SSW with a 28° azimuth, and it is leeward of the island and sheltered, considering predominant wind and wave regime. It is part of a coastal subsystem also integrated by Dickenson Bay and Fort Bay beaches, limiting to the north with the waters that separate Antigua from Barbuda, and to the south, with Saint Johns Harbor.

According to its morphology, and degree and type of anthropization, Runaway Bay Beach can be subdivided, for better study, into four sectors (Plan 1A).

Sectors 2 and 4 have coastal defense structures, high anthropization levels and present the worst beach quality.

Sector 3 is supported by a breakwater pier situated immediately to the south and preserves a narrow sun strip; the dune is occupied by buildings.

Sector 1, in the center and south of the beach, is the best conserved; though its dune is occupied by buildings at its southern end, and by invasive plant species covering the rest. The beach shows evidence of erosion in the north, and of accretion on its southern end.

References from monitoring carried out since 1995, and previous research, account for the loss of the beach in the north sector, in the mid-1990s, as a result of the impact of Hurricane Luis, after the anthropization of the site had been accelerated, as well as a gradual erosion process that has been sustained since then.

Others references have permitted to detect the advance in the construction of coastal defense works by private initiative, throughout the first two decades of the 21st century, which have had as their main objective the defense of properties, and not the preservation of the beach.

The mean wind regime, given its speed and direction, does not allow to foresee that the wind transport of sediments will have an important stake in the dynamics of the study area, which is in agreement with field observations.

The beach's location, sheltered from the predominant wave regime from the east, and the existence of a relatively extensive island shelf, causes wave energy dissipation processes to predominate, by contact with the seabed, as well as by wave refraction and diffraction, before they reach the study area.

After these complex wave transformation processes inherent to the predominant regime, the beach is reached by waves that strike obliquely from the NW.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

In this scenario:

- A low-intensity longshore transport is established, with great persistence, from NNE to SSW along the entire Sector 1, expressed in the erosion trend evident in its northern limit and the cumulative one in its southern limit.
- Wave reflection processes predominate facing the breakwater structure in Sector 2, which together with the influence of the rocky shoal located in front of it, and the wave diffraction processes that it generates, give rise to slight rip currents.
- Sectors 3 and 4 are reached by lower energy waves, which barely generate currents in the coastal zone, being in agreement with field observations, where no remarkable accretions were registered supported by the pier-breakwater located on the boundary between Sectors 2 and 3.

Sedimentological and dynamic studies allow identifying the proliferation of Halimeda algae, observed on the seabed at depths of 5 m to 15 m, as the responsible for the main sediment input to the coastal system and, particularly, to Runaway Bay Beach.

To a lesser extent, there are also inputs derived from the abrasion of the cliffs adjacent to Dickenson Bay and Runaway Bay beaches.

Due to the impact of wave generated at the passage of tropical cyclones, several circulation cells are established and points with trend to the appearance of rip currents are observed, particularly in the northern limit of Sector 1, immediately south of the breakwater structures, and the northern end of Sector 4.

These last elements enable sediment outputs that explain the permanence of critical areas on the beach, in sectors where rip currents occur, enhanced due to the reflective nature of the defense structures, and other buildings, exposed to storm wave action.

Simulations allow determining that the directions from W to NNE favor sand transport beyond the southern end of Runaway Bay, passing in front of the coastal cliff towards Fort Bay Beach. This sediment transport keeps going farther south, until its gradual deposition in the channel of Saint Johns Harbor, which is dredged periodically.

Meanwhile, the SW direction produces a reverse in the longshore drift along the beach. Although, it should be remembered that the predominant wind and wave regime in the study area has a very high persistence throughout the year, and is characterized by winds and wave from the east that have an incidence from NNE in the grid; while the remaining simulated directions mainly occur during the passage of tropical cyclones, capable of generating large transformations on the beach, though with very low annual frequency.

It is a complex dynamic, with several possibilities according to the wave incident direction and intensity. We have tried to summarize, in its more relevant elements, in the following diagram that opposes the circulation due to the impact of directions of the north component (after the referred wave transformation processes coming from the open ocean), characteristic of the usual regime, highly predominant throughout the year; to the circulation brought about by storm waves generated by tropical cyclones that move relatively close to the south of the island, with directions towards the NW or the north (Fig. 44).

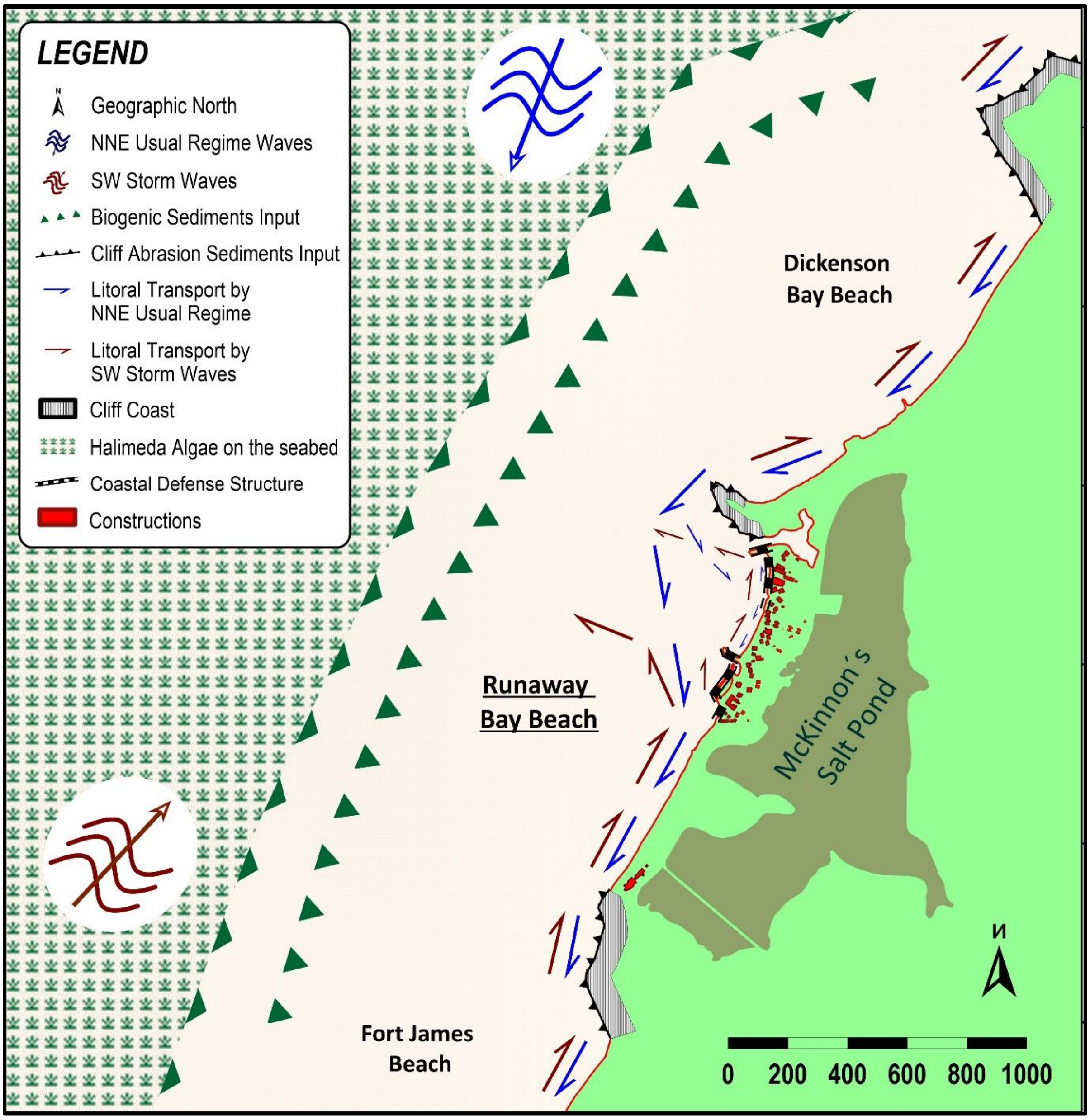


Figure 44: Diagram of the dynamic functioning of the Coastal System composed of Dickenson Bay, Fort Bay, and Runaway Bay beaches, with emphasis on the latter, facing directions of the north component that have an incidence on area, and storm waves from the SW.

V.9.1 Causes of the erosion process.

Based on the referred studies and the results obtained, it is possible to determine that Runaway Bay beach underwent an intense erosion process in the last decade of past century that exceeded its resilience capacity, which resulted in the loss of the whole north sector (4).

Since then, a moderate erosion process has been maintained, with greater intensity at the indicated points, which accelerates during the passage of events that generate higher energy wave, mainly tropical cyclones.

The causes of the erosion process were identified as follows (part of the information resumed in Plan 8):

- Of anthropogenic origin:
  - Occupation of the dune by hard structures that intensify the storm wave reflection processes, favoring the appearance of rip currents and off-shore sediment transport.
  - Occupation of the coastal zone by breakwaters that interrupt the coastal sediment transport and punctually favor the generation, or intensification, of rip currents.
  - Application of layers of technical filling with different materials, on the dune, favoring the stiffening of the ground, and of the dune itself, and partly contributing to the reflection of storm waves.
  - Dredging of the access channel to Marina Bay, which contributes to interrupting the sand transport from Dickenson Bay.
- Of natural origin:
  - Tidal waves generated by tropical cyclones in a new active period started in 1994, in the North Atlantic basin.
  - Shoals and rocky outcrops, causing wave diffraction processes that favor the generation of rip currents in certain areas of the beach.
  - Climate change-induced mean sea level rise.

Additionally, it should be noted the occupation of the dune in Sector 1 by invasive plant species, whose possible effect should be evaluated in the longer term.

VI. REHABILITATION AND MANAGEMENT STRATEGY

The IPCC (2022) analyzes some of the possible adaptation strategies, in the coastal zone, in view of the projected sea level rise (Fig. 45).

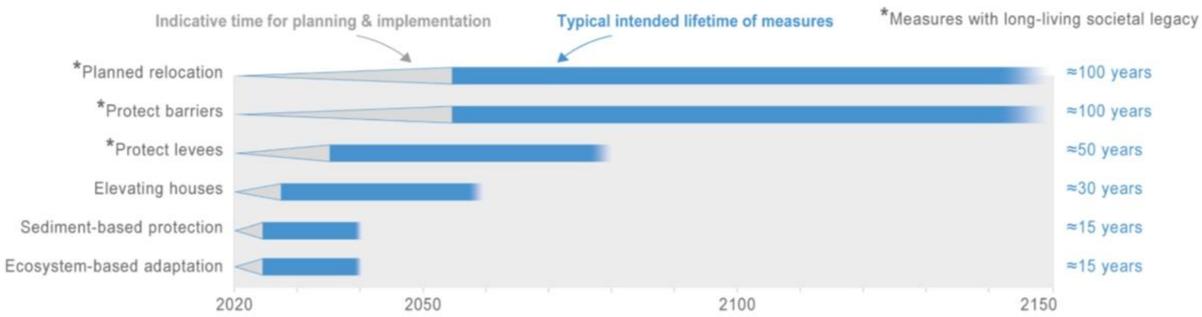


Figure 45: Possible adaptation strategies, in the zone coastal, in view of sea level rise. Recommended timing for implementation and estimated durability (IPCC, 2022).

For the present, it recommends ecosystem-based adaptation measures, or the execution of protection works based on the sediments, such as the application of artificial sand nourishment for the recovery of beaches and dunes.

In the longer term, it recommends the execution of other engineering actions. However, any strategy analysis must start from the characteristics of the coastal zone in question, including the identification of the causes of the erosion process, and guarantee, as much as possible, the recovery and preservation of its natural values, as well as the availability of financing and technology, among other elements of analysis.

In his article "Coastal Protection Measures – Case of Small Island Developing States to Address Sea-level Rise", Wong (2018) summarizes the different actions that have been tested in these countries, for the defense of the coasts against erosion.

Wong (2018) summarizes the topographic characteristics of the coastal zone and the most applied types of solutions, and proposals for 35 countries identified as Small Island Developing States (SIDS). His notes on Antigua and Barbuda are shown in Table 16.

In the case of Runaway Bay, as has been described above, the design and execution of coastal defense structures has certainly been tested; though they seem to have been designed exclusively for the protection of the properties they aim to safeguard, without taking into account a comprehensive approach including the recovery and preservation of the beach, which would also have greater probabilities of success in preserving the referred properties.

Table 16: Existing topographic characteristic and proposed adaptation measures. Antigua and Barbuda. Taken from Wong (2018).

Country	Significant topographic features	Existing adaptation measures	Proposed adaptation measures and options	Comments on EBA* and other aspects
Antigua and Barbuda	Mixed lithology Coral Reefs Beaches Dunes Seagrasses Mangroves	Coastal Defenses Reef and Mangrove Conservation	Flood Defenses Raising Dike Level Projects addressing coastal ecosystems	Existing measures poorly designed Scope for EBA

EBA: Ecosystems-Based Adaptation.

After describing the types of solutions applied, Wong (2018) prepared the first classification of coastal protection technologies for Small Island States (Table 17).

Table 17: Proposal of classification of coastal protection technologies for SIDS (Wong, 2018).

Classif	Protection technology	Assessment for SIDS
A	**Hard structures Seawalls & Dikes** Breakwaters & groins	Costly; deployed for critical structures; for 'no retreat' options; revetments affordable by richer SIDS
B	**Soft structures** Beach nourishment Sand bags	Short-term; for selective deployment, e.g. tourist coasts
C	**Hybrid structures** Living shorelines	Scope for SIDS but generally restricted to lower-energy coasts; research required for deployment to higher-energy coasts. Currently best and wide scope for SIDS; can be combined with hybrid structures; further research required
D	**EBA** Mangroves Coral reefs Dunes	
E	**Topography/elevation** Reclamation Save some islands	Costly; but can be more permanent than "A" category technology
F	**Float** Stilt/elevated homes Floating/amphibious homes Floating islands	Should be considered more seriously given new materials and technologies
G	**Imitate nature** Building with nature Living with water	**Research required for deployment in SIDS**
H	**New and innovative ideas**	To be updated regularly given new materials and technology in future

Regarding Wong's proposals, for their application in Antigua and Barbuda, they are logical in general terms, given that, due to its location, the natural hazards associated with the impact of tropical cyclones, and the effects of change climate in the medium and length term constitute the main concerns for this country. However, a more detailed analysis shows that there are different management strategies with probabilities of success, depending of the type of coast and its direct or indirect exposure to the wave generated and propagated across the open ocean.

For this case, a sandy beach with different degrees of anthropization and types of actions that allow subdividing it into four sectors for its study and design of strategies; and attending to the results exposed and summarized in section V.9, as well as the causes of the erosion identified in section V.9.1, the engineering alternatives grouped into classifications B and D would have greater probabilities of success (Table 18).

Table 18: Proposed Measures for Runaway Bay Beach (table partially included in Plan 8).

Runaway Bay Beach	Significant Elements	Existing measures	Proposed measures	Comments
Sector 1	Smooth slope. Scarped dune covered by invasive plants. Rock outcrops (North). Constructions over the dune (South).		Beach nourishment. Dune recovery. Dune reforestation. Removal of invasive plants species.	Analyze possibility of removing or protecting the foundations of structures on the dune.
Sector 2	Steep slope at the foot of the breakwater. Deterioration of environmental quality in confined area Buildings on the dune. Shoals and rocky heads.	Groynes Breakwaters Revetments	Removal coastal defenses structures. Beach nourishment. Dune recovery. Dune reforestation. Protection of buidings foundations.	If not possible to remove the hard structures, it is recommended to assess the condition of their foundations.
Sector 3	Gentle slope profile. Constructions over dune. Invasive plants occupying the dune. Rock outcrops at North. Shoals and rocky heads.	End of beach Groyne	Beach nourishment. Dune recovery. Dune reforestation. Removal of invasive plants species.	Analyze possibility of removing or protecting the foundations of structures on the dune.
Sector 4	Little area with coarse sand at northern limit. In general the dry beach has been lost. Constructions over dune Shoals and rocky heads.	End of beach Groyne Revetments Wall	Removal coastal defenses structures. Beach nourishment. Dune recovery. Dune reforestation. Protection of buidings fundations.	If the wall is removed, analyze to reconfigure, displace the dune landwards, or protect foundations of vulnerable structures.

VI.1 Short- and medium-term measures.

Although it is always advisable to recover and preserve the natural conditions of the beach, it is understood that, in the short term, it will not be feasible to implement a program for demolition under compensation that eradicates the facilities currently occupying the beach dune, in detriment of its stability, and increasingly vulnerable to the sea action, as a result of the erosion process to which these structures contribute.

Therefore, for the time being, it is necessary to resort to the design of actions that, at same time, contribute to beach recovery, and to protect the facilities occupying the dune.

It is proposed, then, to turn to the immediate execution of a comprehensive artificial sand nourishment project, including dune recovery or enhancement in those sectors where possible, in addition to the eradication of invasive plants and reforestation with species typical of the beaches in the Caribbean region, with a functional approach.

This type of actions, carried out jointly, have shown a high degree of effectiveness, since, through their application, beaches are designed as civil works for the protection of the coastal zone, almost instantly covering the deficit in the sediment volume required for the recovery of beach conditions (part of the information included in Plan 8):

- Morphological: conforming a well-developed and complete profile, with the presence of the different morphological elements that make it up (mainly submerged bars, berms and dunes, reforested with species typical of Caribbean beaches), and a notable increase in the sun strip width.
- Aesthetic: advancing in the gradual restoration of the natural aesthetic and landscape values of the original ecosystem, through the rehabilitation of both the sandy profile and the corresponding coastal vegetation.
- Functional: conceiving a double use value for the recovered beach:
  - *Recreational and Tourist:* the achievement of the aforementioned precepts relative to the conformation of a profile with adequate Sun Strip and Carrying Capacity, and an attractive natural image, will contribute to the beach conditioning for these functions;
  - *Coastal Defense Civil Works:* taking advantage of the essentially dissipative nature of the beaches with sufficient sand volumes to form extensive, gently sloping profiles, with submerged bars and powerful berms, and dunes with sand reserves and appropriate design heights, all to guarantee an efficient dissipation of wave energy typical of strong storm waves generated by extreme weather events.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

The reforestation design, according to the type of plants to be used and their distribution in the profile, will also fulfill its own functions of sand dune stabilization, avoiding their deflation, and even contributing to their accretion by retaining the sand put in suspension by wind action, as well as forming an effective barrier against the landward intrusion of the saline spray, which allows to attenuate its corrosive action on structures and equipment with metallic components.

The recovery of the beach natural aesthetic and landscape values has a positive environmental impact and provides added value to make it attractive and promote its tourist and recreational use.

Since the use of this type of solution is feasible, resorting to other more invasive ones, such as building rigid coastal defense structures, is detrimental to achieving this purpose and, by themselves, they would still not be able to restore the sediment deficit accumulated by the beach as a result of the erosive process suffered to date.

The actions stated and proposed for their short-term execution are also aligned with the implementation of the concepts of Sustainable Development, Sustainable Tourism, and Ecosystem-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 in the medium and long term.

VI.1.1 Sector 2. Requirement of previous definitions.

It will be necessary to define in advance the way of acting in Sector 2, where there are coastal protection structures, whose building derives from private initiative, and which would prevent the execution of the proposed actions in the short term in this area.

For the recovery and comprehensive management of the beach, it is recommended to remove these structures.

On the one hand, the groins interrupt the longshore sediment transport, and the breakwater makes it difficult for new inputs to reach the beach in this sector when coming from the production areas, mainly located in the submerged profile. Moreover, the excessive decrease in incident wave energy in usual conditions has permitted a deficient water circulation, favoring its eutrophication, the proliferation of seagrass in the bathing area and the stiffening of the submerged profile.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

On the other hand, these structures fulfill a certain function to protect the private property they defend when facing extreme events.

The proposed sand fill would make it possible to create a beach with enough sand volume to dissipate wave energy when faced with the design event. While the enhancement and reforestation of the dune, added to the use of sacks made of geotextile material stuffed with sand, or rocks from the current breakwater, for the protection of building foundations facing the most extreme events, would complement each other to replace the current function of the breakwater.

In the most extreme cases, where high waves hit and storm surge generates a sea level rise higher than the dimensions of design, it will not be possible to avoid sea penetration events and impacts on the property, neither with the current structures, nor with the proposed solution.

Instead, the proposed strategy has the advantage of returning its natural values and social usage value to the beach, creating, in addition, the right conditions for its possible use for tourist purposes.

Finally, if it is not possible to remove the defense structures in Sector 2, it would not be possible to carry out any actions in it, and actions proposed for sectors 1, 3 and 4 would be executed in an isolated manner. In such case, it is also recommended to perform an assessment and monitoring of the condition of the breakwater foundations, vulnerable to the undermining action of waves, according to the submerged profile slope measured during the bathymetric survey in the site.

VI.1.2 Short and Medium Term Action Guidelines.

In short, the actions to be carried out, as soon as possible, in the short and medium term, would be:

- Negotiation between authorities and owners, on the strategy to fallow in Sector 2, in relation to the coastal defense structures located there (immediately).
- Negotiation between authorities and owners, for the definition of structures to protect through the placement of either sacks made of geotextile material or elements from the breakwaters to remove (if applicable), as appropriate, they may be supported on the foundations, or as a core of the dune to shape (immediately).
- Sand filling along the entire beach, or in the sectors 1, 3 and 4, if it is decided not to act in Sector 2 (as soon as possible, after negotiations).

- Reshaping or enhancing the dune in the sectors benefited by the sand fill (at the same time as sand nourishment).
- Eradication of invasive plants on the dune and backdune, where necessary (medium term).
- Reforestation of the dune and back dune, where necessary (after removal of invasives).
- Protection of the foundations of the defined structures, when facing extreme erosion events, through the use of sacks made of geotextile material stuffed with sand, or items of the breakwaters to be removed (if applicable), as appropriate (medium term).

The chronological order of the proposed actions may vary depending on the real possibilities. The design of the proposed actions is set out in the next chapter.

VI.2 Long term measurements.

The long-term strategy will necessarily be linked to the expected effectiveness, subsequently verified through monitoring, of the measures to be executed in the short and medium terms.

This strategy will then be marked by the expected and subsequently verified rhythm of shoreline retreat, related in turn with the return period of extreme events able to generate the main erosion events on the beach, and with sea level rise induced by global climate change.

The approach of Small Island Developing States (SIDS) strategies for confronting climate change is essentially adaptive.

For many countries, the adaptation happens, essentially, by the design of strategies for a gradual retreat from the most vulnerable areas, adjusted to the foreseeable rhythm of sea level rise and the monitoring of 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. That is, in general, the situation in Antigua and Barbuda.

As has been mentioned, the mean sea level rise the generates, by itself, an additional demand of sediments for hold the dynamic equilibrium profile of the beach and avoid shoreline retreat. The island shelf of Antigua and Barbuda, probably contains and continues producing sufficient sand volumes to maintain this equilibrium, but, under current conditions, it is very unlikely that coastal dynamics favor the necessary transport of these sediment volumes from the production areas towards Runaway Bay Beach. Therefore, the periodic application of artificial sand nourishment seems to be the essential element of the management strategy in the long term, for confronting the effects of erosion in the study area.

Based on all of the above, and since it has been determined that erosion at Runaway Bay Beach results from the combination of anthropogenic and natural causes, including possible effects of the Climate Change, the following would be essentials elements for the long-term management strategy (part of the information included in the Plan 8):

- Creation of the institutional and legal framework that promotes and guarantees the implementation of strategies and actions, aimed at the gradual restitution of the beach natural conditions, eliminating the anthropogenic elements that contribute to its erosion.
- Monitoring of the effectiveness of the executed actions that make up the short and medium term strategy, and in general, of the beach evolution, to define when new actions are required.
- Periodic application of Artificial Sand Nourishment to solve, almost immediately, the deficit in the input of sediment volume required by the beach to reach its dynamic equilibrium.
- Others actions, such as those directed to the maintenance and protection of the dune and its vegetation coverage, or of the works to protect the foundations of the buildings that remain in the area, will be evaluated, designed and executed as appropriate.

Wong (2018) highlights the positive example of Barbados that has created a Coastal Zone Management Unit, whose work includes the design and execution of harsh and soft engineering measures for the protection, stability and improvement of beaches.

The implementation of the Integrated Coastal Management Program for Varadero Beach, in Cuba, is also an example that stands out in the region, as well as the National Investment Program for Beach Recovery, which is part of Cuban State Plan for Confronting Climate Change (Fig. 46). All this was preceded by the implementation of Decree-Law 212, for Coastal Zone Management, which was written in consultation with the Cuban scientific community and taking references of foreign legislation at the forefront in these topics at the time.

Figure 46: Components of the Integrated Management of Varadero Beach, assumed by the local Office for Integrated Coastal Management, under the Cuban Ministry of Science, Technology and Environment.

VII. DESIGN OF THE PROPOSED SOLUTION

VII.1 Artificial Sand Nourishment.

In the last decades of the 20th century, the application of artificial beach nourishment started 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, in the Black Sea, the failure of several 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 among 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 already reports of 60 beaches on the Atlantic coast, 35 on the Gulf coast and 30 on the Pacific coast, which had been, or were being periodically benefited by the application of artificial beach nourishment. It was then estimated that these works had exceeded the order of 300 million m^3 of sand discharged for the recovery of more than 600 km of shoreline (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 Caribbean area, Cuba has been a pioneer in the application of this technique for the recovery of its beaches, highlighting in particular the example of Varadero, which has been subject to the discharge of more than 3.5 million m^3 of sand, between 1987 and 2020, underlining the project executed in the summer of 1998, with 1,087,000 m^3 of sand along 12 km of the 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 the beach erosion; the removal of Australian pines from the coastal zone; the reshaping and reforestation of several kilometers of dunes; and the building of rustic wooden walkways to provide access to the beach to guarantee the preservation of the 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 the Recovery of Beaches in Cuba, later integrated into the Cuban State Plan to Confront Climate Change (known as 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 opportunity.

On Cancun Beach, in Mexico, the discharge of more than 5.2 million m^3 of sand between 2009 and 2010 stands out, 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 start their execution, for almost 7 million m^3 of sand in total to be filled for the recovery of Cancun and Carmen beaches, and others on 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.

As discussed in the previous chapter, the application of artificial beach nourishment in Runaway Bay Beach aims to restore, almost instantaneously, the deficit of sediments that the beach has accumulated as a result of the erosive process that it has faced, returning its natural values; guaranteeing that it has the necessary volumes of sand to dissipate the energy of the waves generated by extreme weather events, thus fulfilling its function as a coastal defense work; and enhancing its use value for recreation and tourism.

For this purpose, it was necessary to define a borrow area with the necessary sand volume and sand characteristics compatible with the beach native sand, and calculate the design parameters of the project, as well as anticipate the technology to be used and estimate the execution costs.

VII.1.1 Borrow Area.

Based on the tasks carried out before beginning the field works, several areas had been defined along the coast, from Dickenson Bay to the “Sandy Islands”, which should be explored with the objective to select the most suitable to be used as borrow area for a possible beach restoration project through the application of artificial sand nourishment.

After the initial exploration, a polygon was defined with an area of 130,000.0 m^2 and a perimeter of 1465.7 m. The proposed borrow area is beyond the calculated closure depth for the active profile of Runaway Bay Beach or the adjacent ones, so that its dredging will not affect the stability of these beaches and the sand fill will constitute an input of new sediments to the profile, and not a redistribution of the sediments in the same profile.

Likewise, the borrow area has the depth required to use trailing suction hopper dredgers with capacity to store large sand volumes, and it is located at a suitable distance from the filling area, to guarantee the economic feasibility of the project execution.

The coordinates of the vertices of the polygon that delimits the proposed borrow area and its location are shown in Table 19 and Figure 47.

The reconnaissance of the defined polygon was completed, including the bathymetric survey (Plans 3 and 4) and 66 diving stations.

The bathymetric survey and reconnaissance by diving allowed verifying that it is an area with a sandy seabed, regular bathymetry, with smooth slope, depths from 11.0 m to 15.0 m under mean sea level, and without obstacles like rocky outcrops or coral reefs.

At each diving station, the thickness of the sand layer was measured, obtaining 1.65 m of material with suitable characteristics for its use in beach recovery, in a first assessment. Table 20 shows the volume of mineral resource identified and measured in Great Sister resource block, estimated from the measured thicknesses.

Table 19: Coordinates of the vertices of the polygon that delimits the borrow area.

"GREAT SISTER BASIN" VERTEX COORDINATES				
Vertex	Antigua 1943 (BWIG)		WGS - 84	
	X	Y	Lat.	Long.
1	413788.255	1897156.264	17.16140	-61.87252
2	413504.843	1897361.636	17.16326	-61.87519
3	413482.545	1897501.288	17.16452	-61.87539
4	413901.503	1897568.181	17.16513	-61.87145
5	414022.965	1897480.164	17.16433	-61.87031
6	413788.255	1897156.264	17.16140	-61.87252

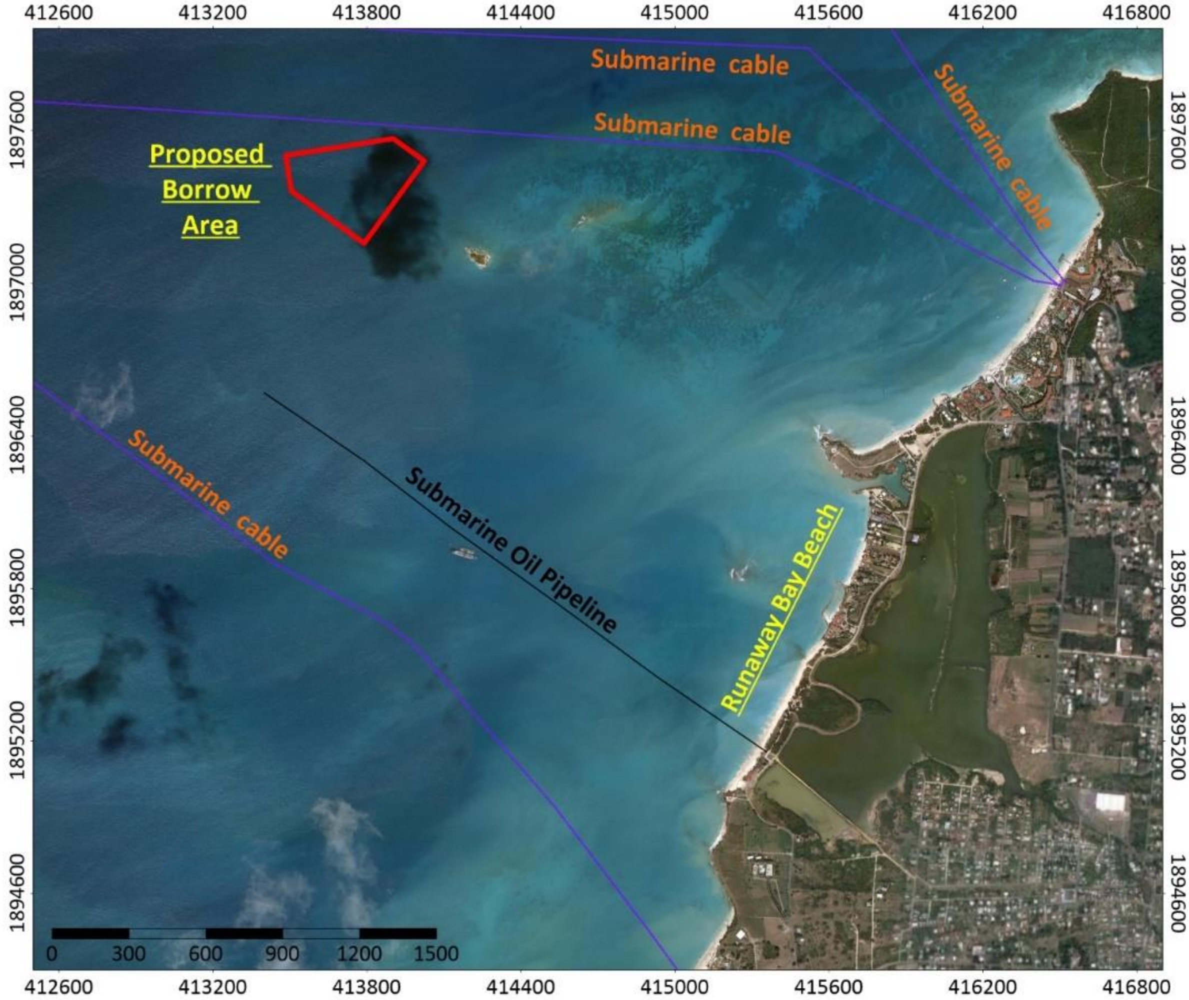


Figure 47: Relative location of Runaway Bay Beach and the proposed borrow area, as well as some obstacles on the seabed that must be taken into account during the execution of project.

Table 20: Mineral resource identified and measured in the borrow area.

BORROW AREA	Area (m^2)	Mean Layer Thickness (m)	Volume (m^3)
Great Sister Basin *Mineral Resource Identified and Measured*	130 000	1.65	214 500

VII.1.2 Characterization of the Marine Biota.

Six diving transepts were performed in the proposed borrow area, directed by MSc. Linnet Busutil, a marine biologist at the Cuban Institute of Marine Sciences.

The specialist was able to verify the predominance of soft sandy bottoms with low biodiversity, partly colonized by macroalgae, mainly of Halimeda type, whose species is a producer of biogenic sediments like those found on the site, according to preliminary results of the composition analysis of sand samples.

The rest of the team confirmed the observations made by the specialist during the diving stations carried out throughout the basin, spread out every 50 m.

The healthy condition of the populations found, in spite of the high water turbidity, allows to predict a high adaptation capacity, and a minimum impact of the dredging works, even more so, considering their punctual character in space and time.

VII.1.3 Characterization of the resource.

The grain size analysis done of the 64 samples collected in the borrow area showed that coarse sand predominates, particularly in its south limit. Plan No. 5 represents the grain size distribution within the borrow area, and the result of laboratory analyses are shown in Tables 21 and 22 (Annex II).

The composition analyses done to six samples taken from stations spread within the borrow area confirmed the biogenic origin of the sand (Table 23).

In the proposed borrow area, "Great Sister" basin, the sand is 100% biogenic, of light gray color, with a predominance of the group of calcareous algae remains, followed by mollusks remains, unidentified bioclasts and foraminifera. None of the analyzed samples included remains of mineral or terrigenous origin. "Others Groups" include annelids, remains of crab claws, sponge spicules, and others poorly represented.

In the group of Unidentified Bioclasts, between 50% and 60% turned out to be conglomerates, grains made up of smaller ones joined by a calcareous matrix. Therefore, the percentages of this group seem relatively high.

In general, sand grains appear quite unpolished, with angular edges and without brightness, with abundance of recent inputs, which indicates a low sediment maturity.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

Table 21: Borrow area. Distribution by sample, by sieve.

Samples Borrow Area	Sieve Ranges							
	>4	4-2	2-1	1-0.5	0.5-0.25	0.25-0.125	0.125-0.063	< 0.063
109	6	9.2	14.5	20.6	25.2	16.3	4.6	3.4
110	1.7	5.9	11.4	21.3	34.3	19.5	2.9	2.8
111	13.1	11.1	16.1	21.2	23	10.7	3	1.7
112	4.4	5.9	13.2	23.3	32.5	17.1	1.9	1.4
113	9.8	13.2	20.5	24.4	20.3	8.6	1.5	1.5
209	1.9	8.2	13.9	22.8	31.8	16.9	2.8	1.6
210	6.7	15.3	21.7	27.6	19.8	6.6	1.8	0.3
211	12.8	12.3	17.5	23.9	23.4	7.2	1.9	0.9
212	5.1	10.9	18.9	25.7	28.2	9.3	1.1	0.6
213	14.1	13.8	21.4	26.6	18.4	4.2	0.9	0.5
214	13.4	15	23.5	28.4	16.4	2.5	0.5	0.1
309	3.3	4.4	11.4	22.8	34.5	17.6	3.2	2.6
310	1.7	3.8	12.2	22.4	36.1	21.2	1.1	0.8
311	1.9	3.8	11.5	23.7	39.5	17	1.4	0.9
312	2.2	6	13.9	27.5	24.5	12.4	1.7	1.5
313	1.2	5.1	16.7	33.2	34.3	7.2	0.9	1.1
314	2	5.9	18.6	34.8	29.8	5.9	1.4	1.5
315	2.3	8.1	23	34.1	26.1	4.9	0.4	0.8
409	7.8	9.9	15.7	29.8	30	5.3	0.7	0.6
410	4.9	8.9	17.4	34.4	28.1	4.6	0.9	0.6
411	13.7	15.3	20.7	28.4	17.7	2.5	1.2	0.4
412	14.5	12.7	21	33.7	16.1	1.3	0.3	0.3
413	9.8	10.3	22.7	34.7	19.2	1.9	0.8	0.4
414	10.2	14.6	25.1	31.4	15.8	1.6	0.8	0.4
415	18.1	18	25.7	24.8	10.6	1.6	0.9	0.3
416	4.8	14.1	30.4	33.2	15.1	1.4	0.4	0.5
509	1.1	3	9.6	23.2	39.3	17.5	3.2	2.8
510	2.3	5.1	16.7	34.2	31.6	7.2	1.2	1.5
511	10.1	11.1	21.6	33.4	19.9	2.4	0.9	0.4
513	0.00	20.90	13.60	21.10	30.20	12.40	0.90	0.50
514	1.6	5.2	21	39.4	25.4	3.2	2.1	2
515	1.2	7.6	20.8	38.3	26.3	3.5	1	1.2
516	9.6	13.3	25.4	32.4	16.1	2	0.9	0.1
517	10.5	12.8	25.1	32.4	16.3	1.8	0.6	0.4
609	1.8	8.4	17.2	30.5	28.8	9.2	2.6	1.3
610	17.1	13.1	21.3	30	14.7	2.4	0.9	0.2
611	5.7	10.2	22.4	38.7	18.9	2.2	1.1	0.6
612	9.8	13.4	26.4	35.1	12.7	1.3	0.8	0.2
613	8.3	10.8	25	39.7	14.3	1	0.6	0.2
614	12.5	11.7	25.1	35.3	12.3	1.4	1.2	0.2
616	1.8	6.1	18.6	40.1	27.4	4	0.7	1.2
617	9.1	16	28.6	32.5	11.4	1.2	0.6	0.4
709	1.7	5.1	17	37.8	28.6	6.5	1.6	1.5
710	2.8	6.4	16.6	36.3	27.4	6.1	1.9	2
711	2.6	6.2	17.4	39.7	27.4	4.2	0.9	1.3
712	10.7	18.5	29.8	29.6	9	1.2	0.9	0.2
713	1.1	4.2	9.8	25.7	36.9	13.7	4.8	3.8
714	6.3	8	19.2	37.8	22.1	4	1.3	1.1
715	1.5	4.8	16.3	36.8	31.6	5.5	1.4	2
716	9.2	12.6	33.8	36.9	6.6	0.5	0.2	0.1
717	3.7	6.6	26.1	50.3	12.4	0.3	0.1	0.3
809	33.8	19.9	21.8	15.8	6.4	1.7	0.6	0.1
810	22.4	25.5	23.8	15.8	7.4	2.7	1.8	0.4
811	21.6	17.6	25	25.4	8.2	1.3	0.5	0.2
812	4.5	11.5	28.8	30.8	15.6	4.9	2.1	1.7
813	8.8	10.2	18.9	28.6	20.6	7.3	3.5	2
814	19.4	19.2	23.3	22.8	10	2.7	2.3	0.4
815	6.6	10.9	27	38.5	12.9	2.4	0.7	0.8
816	2.6	13.1	30.3	40	11.2	1.3	0.7	0.6
817	3.5	11.4	40.5	40.3	3.8	0.1	0.1	0.2
1110	9.6	18.9	29	24.7	11.4	3.3	2.3	0.7
1111	10.5	11.9	16.8	24.5	25.3	8.2	1.7	0.9
1112	7.4	9.1	13.2	20.7	27	15.7	3.5	3.1
1211	6.4	7.1	16.6	25.4	24.7	12.2	3.7	3.7
TS GS NW	6.25	9.31	17.07	25.44	26.66	11.11	2.01	1.47
TS GS Center	6.85	10.45	21.31	33.87	21.22	4.09	1.16	0.88
TS GS SE	13.69	15.48	26.60	28.67	10.68	2.71	1.37	0.71

Table 22: Borrow area. Main statistics and classification of according to grain size.

Samples Borrow Area	Percentiles		M		Statistics			Classification
	D50	D90	(mm)	(Ø)	Standard Dev. (Ø)	Asymmetry	Kurtosis	
109	0.5068	2.96	0.558	0.843	1.672	-0.103	2.592	Coarse Sand
110	0.4118	1.73	0.451	1.149	1.383	-0.225	3.227	Medium Sand
111	0.7294	4.72	0.798	0.325	1.718	-0.015	2.361	Coarse Sand
112	0.4685	2.08	0.536	0.899	1.419	-0.412	3.136	Coarse Sand
113	0.8338	3.96	0.861	0.216	1.568	0.115	2.670	Coarse Sand
209	0.4668	2.02	0.520	0.944	1.393	-0.203	2.898	Coarse Sand
210	0.8558	3.45	0.888	0.171	1.414	0.054	2.617	Coarse Sand
211	0.8080	4.66	0.892	0.165	1.595	-0.034	2.438	Coarse Sand
212	0.6673	2.93	0.725	0.465	1.391	-0.199	2.713	Coarse Sand
213	0.9832	4.90	1.071	-0.099	1.480	0.030	2.517	Very Coarse Sand
214	1.0608	4.77	1.153	-0.205	1.368	-0.073	2.386	Very Coarse Sand
309	0.4258	1.74	0.468	1.096	1.408	-0.309	3.423	Medium Sand
310	0.4162	1.55	0.465	1.105	1.228	-0.526	3.393	Medium Sand
311	0.4273	1.55	0.478	1.066	1.211	-0.508	3.678	Medium Sand
312	0.5636	1.92	0.570	0.811	1.344	-0.052	3.216	Coarse Sand
313	0.5709	1.72	0.593	0.753	1.142	-0.035	3.815	Coarse Sand
314	0.6268	1.85	0.636	0.654	1.215	0.116	3.917	Coarse Sand
315	0.7158	2.07	0.736	0.442	1.175	0.004	3.539	Coarse Sand
409	0.6813	3.43	0.778	0.362	1.382	-0.369	2.890	Coarse Sand
410	0.6861	2.69	0.745	0.425	1.269	-0.284	3.320	Coarse Sand
411	0.9939	4.83	1.106	-0.146	1.444	0.042	2.586	Very Coarse Sand
412	0.9646	4.96	1.142	-0.192	1.354	-0.191	2.544	Very Coarse Sand
413	0.8678	3.95	0.971	0.042	1.311	-0.193	3.040	Coarse Sand
414	0.9989	4.06	1.087	-0.120	1.315	0.012	2.966	Very Coarse Sand
415	1.3747	5.45	1.398	-0.483	1.392	0.276	2.769	Very Coarse Sand
416	0.9865	3.10	1.014	-0.020	1.163	0.130	3.583	Very Coarse Sand
509	0.3979	1.31	0.417	1.263	1.250	-0.117	3.766	Medium Sand
510	0.5928	1.80	0.608	0.718	1.218	-0.009	3.931	Coarse Sand
511	0.8630	4.03	0.967	0.048	1.344	-0.168	2.910	Coarse Sand
513	0.2000	0.00	1.363	-0.447	1.408	-0.007	2.288	Very Coarse Sand
514	0.6773	1.80	0.660	0.599	1.200	0.491	4.525	Coarse Sand
515	0.6919	1.92	0.700	0.515	1.142	0.248	4.125	Coarse Sand
516	0.9663	3.92	1.055	-0.077	1.288	-0.106	2.795	Very Coarse Sand
517	0.9674	4.14	1.064	-0.090	1.309	-0.069	2.955	Very Coarse Sand
609	0.5997	2.04	0.612	0.708	1.313	0.056	3.206	Coarse Sand
610	1.0552	5.34	1.198	-0.260	1.436	-0.016	2.435	Very Coarse Sand
611	0.8124	2.99	0.876	0.190	1.234	-0.053	3.626	Coarse Sand
612	0.9951	3.96	1.104	-0.143	1.248	-0.078	3.068	Very Coarse Sand
613	0.9029	3.59	1.019	-0.027	1.192	-0.269	3.262	Very Coarse Sand
614	0.9893	4.60	1.123	-0.167	1.313	-0.064	3.001	Very Coarse Sand
616	0.6667	1.85	0.678	0.561	1.130	0.100	4.324	Coarse Sand
617	1.0965	3.85	1.156	-0.209	1.235	0.102	3.318	Very Coarse Sand
709	0.6196	1.76	0.615	0.701	1.190	0.168	4.075	Coarse Sand
710	0.6330	1.94	0.635	0.655	1.290	0.151	3.924	Coarse Sand
711	0.6617	1.91	0.678	0.561	1.177	0.028	4.264	Coarse Sand
712	1.2343	4.19	1.267	-0.341	1.244	0.197	3.201	Very Coarse Sand
713	0.4206	1.43	0.428	1.223	1.338	0.063	3.511	Medium Sand
714	0.7403	2.91	0.789	0.342	1.315	-0.058	3.650	Coarse Sand
715	0.5974	1.71	0.597	0.744	1.187	0.235	4.321	Coarse Sand
716	1.1228	3.83	1.215	-0.281	1.087	-0.285	3.246	Very Coarse Sand
717	0.8302	2.07	0.907	0.140	0.961	-0.433	4.742	Coarse Sand
809	2.2711	6.52	2.012	-1.009	1.406	0.677	2.810	Fine Gravel
810	1.8868	5.87	1.652	-0.725	1.479	0.791	3.356	Very Coarse Sand
811	1.4866	5.81	1.538	-0.621	1.363	0.237	2.579	Very Coarse Sand
812	0.8906	2.87	0.852	0.231	1.375	0.501	3.700	Coarse Sand
813	0.7467	3.69	0.769	0.379	1.583	0.130	2.898	Coarse Sand
814	1.4227	5.59	1.375	-0.459	1.517	0.484	2.891	Very Coarse Sand
815	0.9074	3.23	0.971	0.043	1.228	0.134	3.944	Coarse Sand
816	0.9347	2.71	0.973	0.039	1.083	0.351	4.496	Coarse Sand
817	1.0978	2.70	1.139	-0.188	0.887	-0.167	4.727	Very Coarse Sand
1110	1.1978	3.94	1.133	-0.180	1.419	0.511	3.336	Very Coarse Sand
1111	0.7388	4.14	0.822	0.282	1.556	-0.115	2.509	Coarse Sand
1112	0.5093	3.29	0.584	0.777	1.672	-0.167	2.631	Coarse Sand
1211	0.5826	2.82	0.595	0.749	1.619	0.026	2.892	Coarse Sand
TS GS NW	0.629	3.041	0.677	0.563	1.497	-0.122	2.830	Coarse Sand
TS GS Center	0.798	3.275	0.855	0.226	1.339	-0.021	3.329	Coarse Sand
TS GS SE	1.164	4.824	1.195	-0.257	1.413	0.319	3.209	Very Coarse Sand

Table 23: Results of composition analysis of the sand from Great Sister basin.

Composition of Sand Samples from Great Sister Basin						
Sand Sample	Calcareous Algae (%)	Mollusks (%)	Foraminifera (%)	Bioclasts (%)	Inorganic Remains (%)	Other groups (%)
112	70.8	16.1	2.2	9.8	0.0	1.2
310	73.2	14.8	4.0	7.0	0.0	1.0
412	65.0	18.3	4.7	11.0	0.0	1.0
515	70.4	16.5	4.6	7.8	0.0	0.8
710	67.4	17.0	5.3	9.0	0.0	1.3
815	70.2	14.1	5.1	10.0	0.0	0.6

VII.1.4 Suitability of the sand to use.

For its physical properties and composition, the sand in the borrow area is suitable to be used in the artificial sand nourishment for the recovery of Runaway Bay Beach.

The main difference is given by the medium grain size; however, a greater size increases the stability of the beach, since it is necessary the impact of waves with higher energy to put the sand grain in suspension. Nevertheless, the area has been subdivided so that it is possible to define specific dredging zones, according to the beach sector to benefit (Table 24).

Table 24: Grain size of type samples in the sectors of Great Sister basin and those corresponding to benefit from the sand filling in Runaway Bay Beach.

Runaway Bay Beach					Great Sister Basin				
Sector	M (mm)	M (ϕ)	Stand Dev (ϕ)	Classification	Sector	M (mm)	M (ϕ)	Stand Dev (ϕ)	Classification
1	0.212	2.235	0.772	Fine Sand	NW	0.677	0.563	1.497	Coarse Sand
2 and 3	0.198	2.334	0.594	Fine Sand	NW	0.677	0.563	1.497	Coarse Sand
4	0.647	0.629	1.306	Coarse Sand	Center	0.855	0.226	1.339	Coarse Sand

A larger sand grain size is associated with a higher settling velocity and, therefore, greater stability of the beach. However, Miklen (1968) observed that sand grains composed of biogenic sediments, according to their shape, from a certain size, did not necessarily show a proportional increase in their settling velocity (Fig. 48).

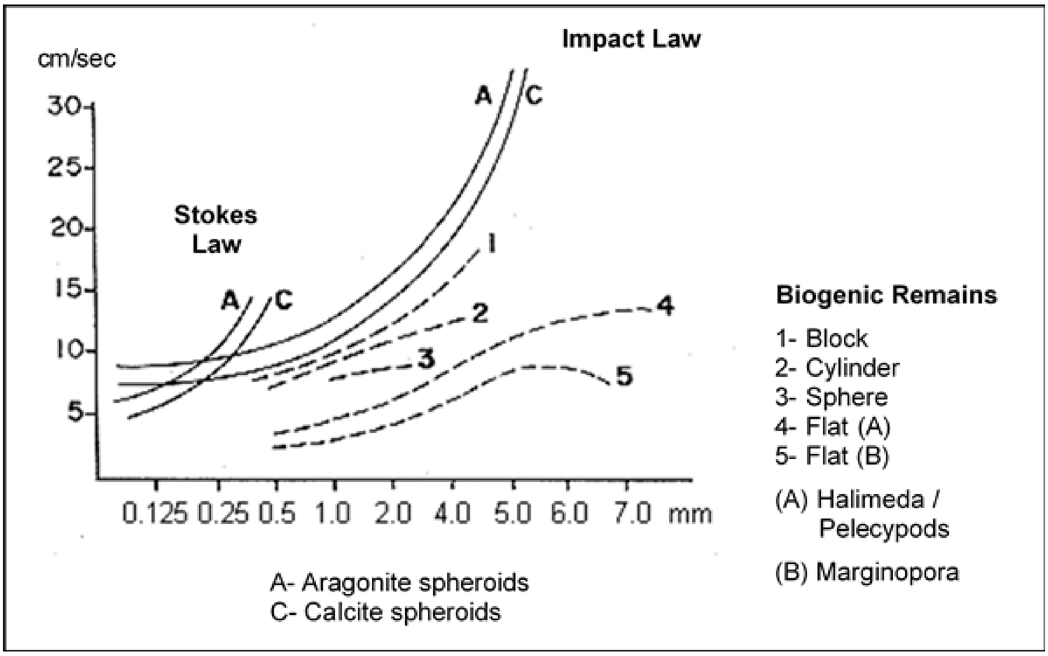


Figure 48: Behavior of the settling velocity for biogenic particles of varied shapes. Miklen (1968), in Stoddart, (1978).

Medviediev and Juanes (1981) carried out an experiment with traps to capture suspended sediments in Varadero Beach, with predominantly biogenic sand. The trap column was situated 4 m deep during four days and horizons at 20, 80, 100, and 200 cm from the seabed were sampled. As shown in Figure 49, the percentage in weight of the 0.5-1.0 fraction turned out to be higher as the separation from the seabed increased.

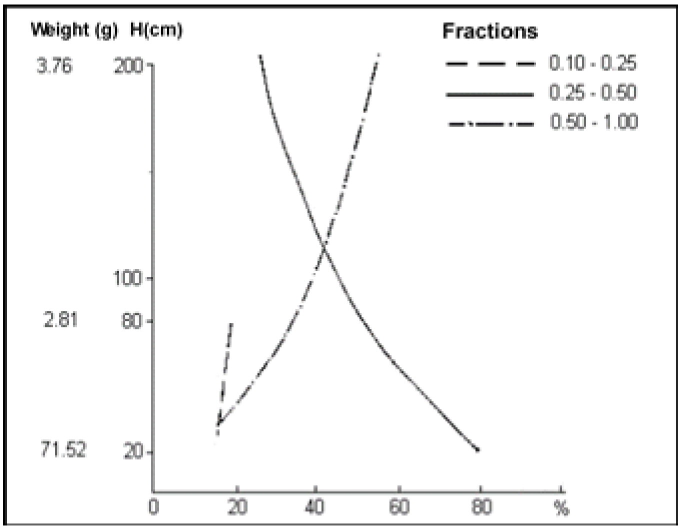


Figure 49: Example of the distribution of sand fractions in an experiment with suspended sediment traps. Medvediev and Juanes, (1981).

These results are associated with the porosity and shape, often flattened, of the biogenic sand grain, that from a certain size, favor its being put and remain in suspension, contrary to what would happen with grains of other origin and with spheroidal shape.

On the other hand, the lower hardness of calcite, particularly sand grains formed by remains of Halimeda algae (component of about 70% of the sand in borrow area), allow to anticipate certain fractioning of the grain during the dredging and filling, a process that will continue under the wave action in the washing area of the beach.

These elements led to propose the use of Great Sister basin as a borrow area, despite the differences regarding the grain size of the native sand of the beach.

Likewise, in last instance, the resource deposited in the last 50 m from the SE limit of the basin is reserved for use in the last instance. This resource is classified as very coarse sand, more susceptible of be put in suspension, based on consulted research results.

VII.1.5 Calculation of the Overfill Factor.

The methodology proposed by James (1975), in the Shore Protection Manual (1984), allows to calculate the RA factor, from plotting of the calculated parameters for abscissas and ordinates, and its graphic representation in the abacus obtained by this author. RA is the value by which the filling volume previously obtained must be multiplied, with the objective to make up for the predictable losses attending to the differences between the mean grain size of the native sand and the introduced sand.

The values of the abscissa and the ordinate to be plotted in the abacus obtained by James (1975), were calculated according to the methodology set out in section III.5.3.

The values of mean diameter M (ϕ) and standard deviation σ (ϕ) for the sands both in the borrow and the beach were taken from the results shown in Table 24.

The results and the plotting of the parameters are shown in Table 25 and Figure 50.

Table 25: Calculation of the Overfill Factor RA the abacus obtained by James (1975). Starting from the values in Table 24, for sectors 1, 2 and 3 of the beach, RA was calculated assuming the north sector of Great Sister Basin as borrow area; for Sector 4, the data corresponding to the central zone of Great Sister Basin were used.

Sector	M (mm)	M (ϕ)	Stand Dev (ϕ)	Classif.	Abscissa	Ordinate	RA
RBB 1	0.212	2.235	0.772	*Fine Sand*	-2.17	1.94	**1.02**
RBB 2 / 3	0.198	2.334	0.594	*Fine Sand*	-2.98	2.52	**1.04**
RBB 4	0.647	0.629	1.306	*Coarse Sand*	-0.31	1.03	**1.00**
GS NW	0.677	0.563	1.497	*Coarse Sand*			
GS Center	0.855	0.226	1.339	*Coarse Sand*			

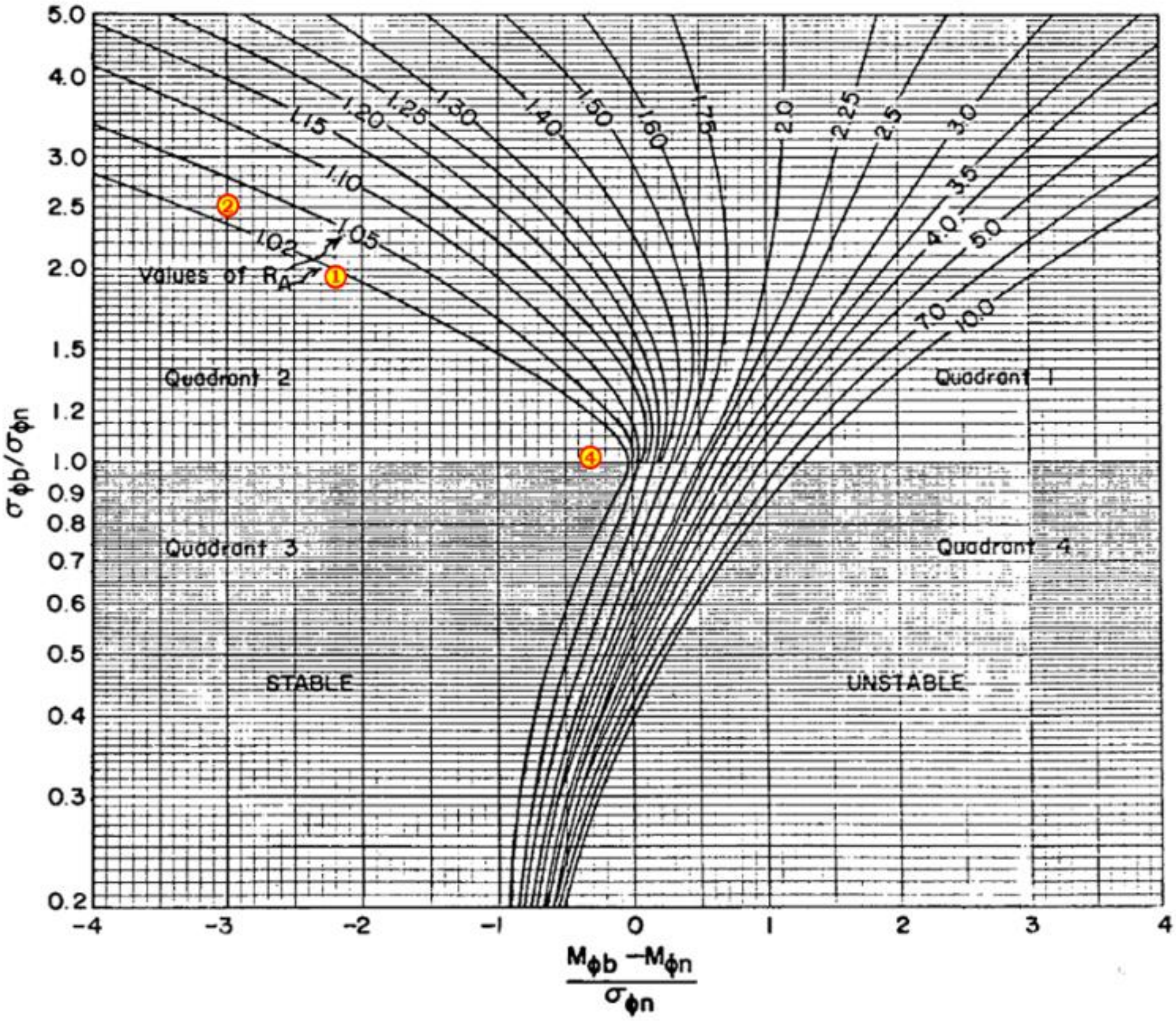


Figure 50. Plotting in the abacus obtained by James (1975) of the parameters corresponding a sectors 1, 2-3 (2) and 4, in Runaway Bay Beach.

The plotting in the abacus shows a shift towards the quadrants that allow to predict the stability of the regenerated profile, so that RA values of around 1.0 are obtained.

VII.1.6 Application of Dean's Method.

The coordinates that limit the sectors in which Runaway Bay Beach has divided for its study, and also for the design of the actions to be carried out, are shown in Table 26 (Plan No. 1A). These are four contiguous stretches that, jointly, add up to 1,300 m of in beach front.

Table 27 shows the results of the application of method proposed by Dean (1991), and exposed in section III.5 above, to each of the sectors into which the sand filling area has been divided. It includes the total filling volume, after multiply by the length of the beach front and the overfill factor corresponding to each case.

Table 26: Limit coordinates of the sand filling sectors.

Sector	Southern Limit				Northern Limit			
	Antigua 1943 (BWIG)		WGS 84		Antigua 1943 (BWIG)		WGS 84	
	X	Y	Lat	Long	X	Y	Lat	Long
1	415219.976	1895032.484	17.142194	-61.859073	415577.945	1895605.948	17.147376	-61.855703
2	415577.945	1895605.948	17.147376	-61.855703	415657.682	1895808.447	17.149206	-61.854952
3	415657.682	1895808.447	17.149206	-61.854952	415737.420	1895985.422	17.150805	-61.854201
4	415737.420	1895985.422	17.150805	-61.854201	415749.295	1896182.816	17.152590	-61.854088

Table 27: Results of the application of Dean's method (1991) for the calculation of filling volume in each sector of the sand filling area.

Sector	Beach Lenght	Depth of Closure	M (mm)	A	Beach Width to Increase (m)	Decision Factor	Are Current and Design Profile Intercepted?	Berm Height (m)	Volume per unit (m^3/m)	R_A	Final Volume per unit (m^3/m)
1	*680*	*7.51*	0.21	0.11	30.00	0.74	SI	1.00	72.47	1.02	*73.9*
2	*220*	*7.51*	0.20	0.11	30.00	0.72	SI	1.00	70.54	1.04	*73.4*
3	*200*	*7.51*	0.20	0.11	30.00	0.72	SI	1.00	70.54	1.04	*73.4*
4	*200*	*7.51*	0.65	0.15	25.00	0.98	SI	1.20	124.18	1.00	*124.2*

VII.2 Dune Design.

For the design of the dune, two criteria were analyzed, whose results should not necessarily coincide.

From the geomorphodynamic point of view, it is valid to reproduce the dune type profile of the beach, extrapolating the model from the sectors where it is conserved, towards those in which it is required to recover it.

From the engineering viewpoint, an analysis of the different sea level components, facing the impact of extreme weather events, when the dune is designed not only as a morphodynamic element of the beach profile, but also as work for defending the facilities located landward.

In the first case, there is the dune stretch still preserved in good part of Sector 1 of the beach.

The second case include the southern end of Sector 1, and the entire sectors 3 and 4, which have facilities that, due to their location, are vulnerable to the impact of extreme events of sea penetrations.

Sector 2 would also be in a similar situation, in case it is decided to remove the breakwater structure, as recommended, to recover its beach.

For these last cases, the design height of the dune can be calculated based on the possible confluence of the maxima of storm surge and wave height in the breaking zone, for the extreme event with return period of 10 years, added to a high tide of 0.30 m, higher than 99% of the annual records (See III.4.2).

The calculation of the storm surge was carried out by applying the parametric method exposed in section III.4.4. The results are shown in the Table 28.

Table 28: Surge of the Tropical Cyclone with return period of 2, 10 and 100 years.

Tropical Cyclone	Classification	SMW (km/h)	SS(m)
Tr 2 Years	*Tropical Storm*	99.0	***0.91***
Tr 10 Years	*Hurricane Cat 3*	192.0	***2.85***
Tr 100 Years	*Hurricane Cat 5*	287.0	***6.10***

The height of the dune design height, calculated from the addition of the previously defined events, is shown in Table 29.

Table 29: Elevation of the design dune with respect to the mean sea level.

Components	Height (m)
High-Tide	0.30
H_B (TC with Tr of 10 years)	1.50
SS (TC with Tr of 10 years)	2.85
Design Level (MSL)	**4.65**

The dune base was calculated guaranteeing a 3m ratio in the horizontal by 1m in the vertical on its seaward face, from the top to the level of the design berm, and 45o slope landward, where it will be supported by the existing dune. With these precepts, it was adjusted to an inverted parabolic function. This method has been successfully tested in dune rehabilitation projects executed in Varadero Beach in the last years, designed by specialists from GAMMA and the Environmental Services Center in Matanzas, Cuba.

The mean volume added as a result of dune conformation with the specified dimensions, for the case study, is 25 m^3/m.

VII.3 Filling Volume.

The volume to be filled per beach sector was calculated taking into account the characteristics and the strategy defined in each case, from the sum of three components:

- Fill volume required for predefined shoreline advancement, from the application of Dean's method (1991) (See Table 27).
- Volume required for dune conformation in the sectors where it is proposed its recovery and reshaping to serve as defense works for structures located landward (25 m^3/m).
- Additional volume resulting from a significant deficit of sediments necessary to guarantee the dynamic equilibrium of the profile (See IV.5).

In this last component, the difference between the equilibrium profile measured at the foot of the breakwater in Sector 2, and the theoretical equilibrium profile is 56.4 m^3/m. Given the situation of the beach and the steep slope that would remain once the breakwater is retired (if so decided), it is proposed to add a volume equivalent to that estimated for the sector.

Given the direction of coastal sediment transport, it is proposed not to benefit directly the last 180 m of beach to the south of Sector 1, limiting the work area to 500 m, so that the densities estimated for the profiles 1B and 1C are increased proportionally.

Given the preservation condition of the central section of the beach in Sector 1, and the direction of coastal transport in it, in spite of the relatively remarkable difference between the measured profile and the theoretical equilibrium profile, it is not proposed to increase the volume to fill in this profile.

The sand fill volume per beach sector is shown in Table 30. A rounding up of the estimated figures was performed to work with whole numbers.

Plans 6, 6A, 7A, 7B and 7C show the filling sectors, with their proposed absolute densities, as well as the design profile, including the dune (some of this information is included in Plan 8).

Table 30: Fill volume per sector.

Runaway Bay Beach	Beach Lenght	Dean Method Application (m^3/m)	Dune Reclamation (m^3/m)	Breakwater undercut (m^3/m)	Final Density (m^3/m)	Volume of Sand (m^3)
Sector 1	*500*	*100.0*	-	-	*100.0*	50000
Sector 2	*220*	*75.0*	*25.0*	*55.0*	*155.0*	34100
Sector 3	*200*	*75.0*	*25.0*	-	*100.0*	20000
Sector 4	*200*	*125.0*	*25.0*	-	*150.0*	30000
RBB	1120					134100

VII.4 Other actions for the protection of vulnerable structures.

According to the strategy designed for the medium and long term, and based on the results that are obtained from the interaction between authorities and owners, it has been proposed to protect the foundations of the structures that so require in Sector 4, and in Sector 2, if it is decided to implement actions in it.

In the case of Sector 2, the decision of act depends on the demolition of the breakwater structure, so that it is most advisable to reuse the extracted rocky material in the formation of a solid core for the designed dune.

Sector 4 presents a similar situation. If the current structures are preserved, they could constitute a solid core for the dune to be reshaped as part of the sand fill project. In a longer-term strategy that includes the removal of the buildings occupying the dune, it could be anticipated the use of rocky material, from the defense structures, for the conformation of a solid core for the designed dune.

For sectors 1 and 3, the protection of foundations of the buildings that so require will be defined as a result of a longer-term strategy, and particularly of the monitoring of beach evolution. For these cases, it is proposed the use of pyramidal structures conformed by sacks made of geotextile material stuffed with sand, as the core of the dune, or supported on the foundations, always with its base below the mean sea level.

This technology, developed in the 1960s, began to be used in the control of erosion of the Dutch coasts in North Sea, for dykes that were filled hydraulically, thus decreasing the expensive haulage of filling materials. The use of this type of material has achieved great popularity in the last years due to its versatility, its simplicity of placement and of filling, its bass cost and its low environmental impact.

This method involves the use of sacks made of high-endurance geosynthetic material. The sacks are elongated and permeable; they are filled with a mixture of soil, silt or sand (20%) with water (80%), where the solid granular part is retained and the water is drained, while the filling is compact.

The fillings used are generally obtained from the same area where the sacks are placed, so for this case it is recommended to use the sand from the beach.

The geotextile material must be specially designed to withstand conditions typical of an aggressive environment, such as salt water, high temperatures and prolonged exposure to sunlight and weathering agents.

The geotextiles shall be woven, since these offer greater mechanical endurance than the non-woven geotextiles.

Both the textile material used for the construction, as well as the seams that join the different cloths, must be able to resist the efforts to which they will be subject during the filling.

Sacks of medium circumference would be used, so it can be admitted that they have two longitudinal seams, one on each side; although it is recommended only one seam that will be situated in the base or bottom, for greater endurance. Likewise, given their dimensions, it is not essential that they have transverse seams along the length of the circumference; however, if so, these would provide greater resistance to the sacks to withstand the stress generated by their own weight when placed one on top of the other by way of a pyramid.

The geotextile material for the sacks shall have, at least, the properties listed in Table 31.

Table 31: General technical requirements of the geotextile material touse.

Properties	Specification
Raw material	Polypropylene or polyester with high tenacity and high resistance to chemical degradation
Resistance to tensile strength (lengthwise and crosswise)	> 10 kN/m
Resistance of the seams	> 10 kN/m
Deformation to tensile strength	< 10 %
Resistance to puncture	> 1 kN/m
Resistance to UV rays	> 20 %
Apparent opening of pores	0.20 – 0.35 hmm

According to Lawson (2008), from the engineering point of view, a first order approximation can be made to the dimensions that a geotube of a given diameter will take, once filled.

The width (W), height (H), the cross-sectional area (A), the contact width of the base with the ground (b) and loads imposed on the support base (□), for a tube full of sand supported on a firm basis, they can be estimated according to the diameter (D) of the tube, using the expressions (Fig. 51):

$H \approx 0.55D$,

$W \approx 1.5D$,

$b \approx D$,

$A \approx 0.6D^2$,

$\delta \approx 0.7\gamma D$

Where: γ is the density of the filling material.

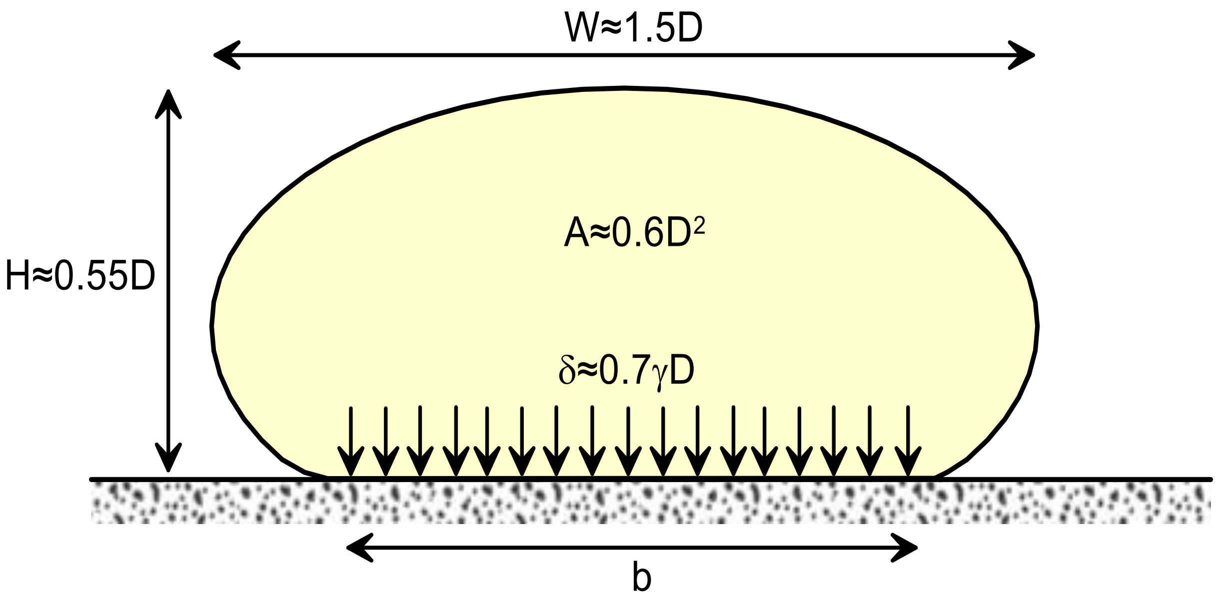


Figure 51: Cross section of a sand filled geotextile tube showing typical dimensions according to the diameter D of the tube and the load on the bed, according to Lawson (2008).

In the western end of Varadero Beach, several buildings were protected with this type of structures in the first years of the 21st century. In 2018, over fifteen years after of their placement, after an erosive event of certain magnitude, the structures were left exposed again, showing an excellent degree of conservation, and still exerting their protective function of the foundations of buildings under their protection (Frame 4).

Frame 4: Four moments of the protection of buildings occupying the dune in the western end of Varadero Beach, Cuba: Previous destruction; start and end of project execution; and exposure of the structures in excellent conservation condition after more than fifteen years, and still fulfilling their function of preserving the foundations of the buildings under their protection.

Based on these general lines and proposed methodologies, when the time comes, the particularized design should be developed for the structures to be conformed to protect the foundations of the buildings that so require.

VII.5 Restoration of the vegetation on the projected dune.

The restoration of the vegetation on the dune is of vital importance for the sustainability of the project, since it contributes to stabilize the profile and favors the sand deposition processes.

The species that were selected to stabilize the dunes, in those sectors where its reshaping is required, will also contribute to restore the minimum ecological conditions for the gradual recovery of flora diversity in the area, once removed the invasive species that occupy part of the area coastal at present.

The restoration strategy for dune vegetation takes into account the natural zoning in plant species, which reflects the different salinity levels of the substrate that they tolerate, where the herbaceous plants are more tolerant to the highest saline aerosol levels.

The present executive project includes only one type profile to shape, with the recommended planting densities and methods for each species to be used. Once the details have been defined and the first sand filling actions and dune conformation have been carried out, a technical task shall be prepared to calculate the number of plants required in each case.

Table 32 shows the species to use and includes the planting method and labors that are planned to be carried out within the framework of the project.

Table 32: Species to be used in the reforestation of the dunes to be restored or shaped. Planting methods and labors.

Species	Method	Planting labor	Time of area preparation before planting
Coccoloba uvífera *Cordia gerascanthus* *Sabal palmetto* *Chrysobalanus icaco* *Thrinax radiata* *Pithecellobium keyense*	Planting holes	- Manual opening of holes - Planting small seedlings after removing the bags - Maintenance of irrigation for the established period	5 days after of the dune is shaped
Scaevola plumieri *Suriana maritima* *Ipomoea pes-caprae* *Toumefortia gnaphalodes*	Agamic sowing	- Sowing of previously rooted cuttings - Maintenance of irrigation for the established period	
Canavalia rosea	Agamic sowing	- Sowing of seeds with previous pregerminative treatment - Maintenance of irrigation for the established period	
Uniola paniculata	Agamic sowing	- Bare root planting - Maintenance of irrigation for the established period	

Table 33 defines the planting frameworks by species, while Table 34 establishes the area in which each species will be used according to its characteristics.

The reforested area will be benefitted from planned irrigation during the first month after planting. During the first fortnight, irrigation will be carried out daily, in the morning or in the evening-night. During the second fortnight, the area will be watered every three days.

Table 33: Planting framework by species.

Scientific Name	Distribution	Planting Method	Planting Framework
Uniola paniculata	Irregular	Tillers with roots	5 /m^2
Scaevola plumieri	Irregular	Rooted cuttings	1 /10 m^2
Suriana maritima	Irregular	Rooted cuttings	1 /10 m^2
Ipomoea pes-caprae	Irregular	Rooted cuttings	10 /m^2
Canavalia rosea	Irregular	Seeds	5 /m^2
Coccoloba uvífera	Irregular	Seedlings	1 /2 m^2
Toumefortia gnaphalodes	Irregular	Rooted cuttings	1 /10 m^2
Cordia gerascanthus	Irregular	Seedlings	1 /20 m^2
Sabal palmetto	Irregular	Seedlings	1 /10 m^2
Chrysobalanus icaco	Irregular	Seedlings	1 /m^2
Thrinax radiata	Irregular	Seedlings	1 /5 m^2
Pithecellobium keyense	Irregular	Seedlings	1 /10 m^2

Table 34: Main species and mixture of species for the area to restore.

Area	Category	Scientific Name
Seaward face of the dune	Main Species	*Uniola paniculata*
	Mixture of Species	*Scaevola plumieri*
		Suriana maritima
Top and landward face of the dune	Main Species	*Coccoloba uvífera*
	Mixture of Species	*Suriana maritima*
		Toumefortia gnaphalodes
	Mixture of Species	*Ipomoea pes-caprae*
		Canavalia rosea
Landward base of the dune	Main Species	*Chrysobalanus icaco*
	Mixture of Species	*Sabal palmetto*
		Thrinax radiata
Backdune	Mixture of Species	*Pithecellobium keyense*
		Cordia gerascanthus
	Mixture of Species	*Ipomoea pes-caprae*
		Canavalia rosea

VIII. EXECUTION MODE AND ESTIMATED TIME

VIII.1 Dredging Works.

As explained in the designed strategy, the first step will be to decide whether to act or not in Sector 2, based on the analysis of the recommendations made in this project, on the part of local authorities and owners of properties located in the area.

All obstacles that obstruct the free movement of heavy equipment in the area of action, and the correct redistribution of the material during the discharge, must be removed. This includes all the umbrellas, kiosks, thatched beachside buildings, nautical equipment and other temporary facilities that can be found on the beach.

The use of a trailing suction hopper dredger is proposed for dredging sand in the borrow area and pumping it onto the beach (Photo 18).

Photo 18: Example of a dredger with characteristics suitable for the execution of this project: Mario Oliva Pérez dredger (Building Company of Maritime Works, Cuba); length 92.95 m, beam 16.5 m, 3,300 m^3 hopper capacity, 6.20 m maximum draft, and power to pump a mixture of 1,280 kg/m^3 up at a distance of 4,500 m.

A trailing suction hopper dredger removes sediment from the seabed while it is kept in motion. Once positioned in the mining area, it deploys the suction arm until it makes contact with the bottom and begins dredging while moving at a very low speed, which, given the dimensions of the basin, should be 2 knots (Fig. 52).

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

Figure 52: Representation of a trailing suction hopper dredger in operation with the arm deployed.

The dredger to use must meet the following requirements:

- Hopper with capacity to store a volume of 2,000 m^3 to 3,500 m^3.
- Maximum draft equal to or less than 7 m.
- Capacity to dredge deeper than 15 m.
- Capacity to pump a mixture of sand and seawater with density higher than 1,000 kg/m^3 at a minimum distance of 1,500 m.

Additionally, it must have:

- Support Tug Boat for maneuvers.
- 1,500 m of floating pipes with an internal diameter of around 0.8 m.

Other resources are also necessary, such as a power generator set and sufficient lights to guarantee round-the-clock operation, marking buoys, etc...

The dredging will always be carried out inside the Borrow Area delimited by the coordinates shown in Table 19, represented in Plan 6.

It will be dredged in straight lines in a NW-SE direction, and vice versa, towards the nearest sector to Great Sister Cay, varying in an ENE-WSW direction towards the farthest sector from the key.

Once the hopper is loaded, the dredger will move to the approach point, following the route suggested in Plan 6. Table 35 shows the coordinates of the approach point for the dredger, and maximum distance to the filling area (Plans 6 and 6A).

Table 35: Coordinates of approach point for the dredger and maximum distance to the beach.

No.	Approach Point				Maximun Distance to the Beach (m)
	Antigua 1943 (BWIG)		WGS 84		
	X	Y	Lat	Long	
1	414766.2	1896050.4	17.15140	-61.86333	1030

The dredging and pumping cycle ends when the dredger is connected to the pipe through which the sand will be propelled by hydraulic processes onto the beach, to shape the final profile with the support of mechanical equipment, according to the design (Fig. 53).

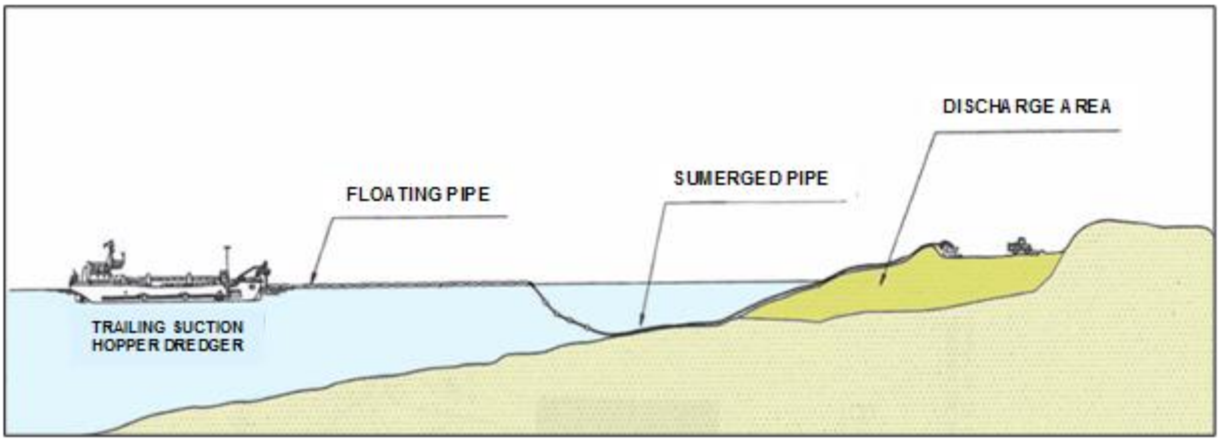


Figure 53: Representation of a dredger connected to the pipe through which it pumps a mixture of water and sand onto the beach to be renourished, where mechanical equipment shape the profile.

To calculate the extracted 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 using 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 of a dredging cycle are shown in Figure 54.

It should be noted that the diagram in Figure 54 shows the phases for both discharge by pipes and by opening the hopper. In the case of this project, the discharge will only be carried out through pipes directly onto the beach (some of this information is included in Plan 8).

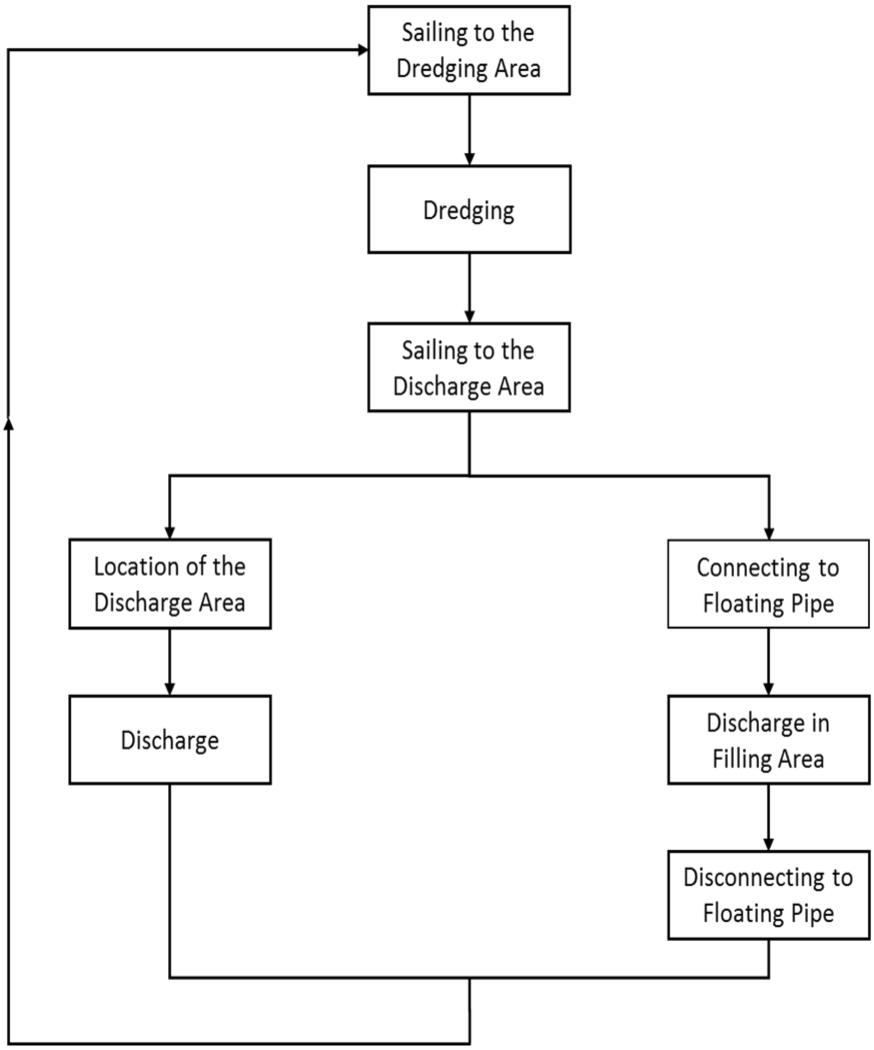


Figure 54: Phases of the dredging cycle.

It is not possible to adequately plan the routes that the dredger will follow within the deposit in each cycle of filling its hopper, without knowing the specific characteristics of the vessel that will undertake the work. This analysis must be carried out jointly between the representatives of the executing agency and the designer, prior to starting the works.

A dredger with a hopper capacity of 2,000 m^3 to 3,500 m^3 requires 30 min to 90 min of continuous dredging for a full load (considering only the operation time). At a speed of 2 knots, the distance required to completely fill the hopper varies between 1.9 km (1.0 nmi) and 5.6 km (3.0 nmi).

If we take into consideration that the proposed borrow area has maximum dimensions of 400 m (in a SW-NE direction) by 450 m (in a NW-SE direction), to complete a dredging cycle the vessel would need to make at least 6 turns within the block, in case of always maintaining the same dredging direction, alternating the coming and going.

Vessels with the aforementioned hopper capacity are 80 m long or longer, and for the turning maneuver would require an amplitude two and a half times greater, which could exceed 200 m.

The relative dimensions of the borrow area and the type of vessel proposed lead to highlight the importance of proper planning of the dredging, to guarantee the correct exploitation of the deposit.

The limitations on the dredger's capacity to maneuver, and safety criteria to avoid accidental mining outside the defined block, mean that, in practice, the corners and edges of the deposit cannot be exploited. For this reason, it is usually required that the identified sand reserve have a volume 25% greater than that required by the project to be executed.

Given that in the polygon defined in the Great Sister basin, a volume of sandy sediments equivalent to 214,500 m^3 has been measured, while the volume required for the recovery of Runaway Bay Beach is 134,100 m^3 of sand, a reserve of 80,400 m^3 would remain, equivalent to 37.5% of the total resource within the deposit.

In order to comply with the discharge on the beach of the projected 134,100 m^3, having dredgers with the defined carrying capacity required, between 38 and 67 dredging cycles must be executed.

Work will be carried out 24 hours a day, taking shifts, without interruption, until completing the sand volume to be discharged according to the executive project.

Once the exploitation of the deposit is finished, it will be monitored on an annual basis for the following 5 years. The monitoring will consist of repeating the bathymetric survey, sampling and sedimentological analysis, and measuring the thickness of the sand layer, and will have the objective of evaluating the natural recovery capacity of the resource volumes, in the basin.

VIII.2 Land Works.

For the works on land, the executing agency must have, at least:

- 1 crawler backhoe loader.
- 1 Bulldozer or crawler front loader.

The access of the pipes and equipment from land to the work area in Sector 4 will be done through of the existing roads in the north end of the beach. Work will be carried out round-the-clock, along the entire shoreline, advancing southwards as the beach profile is being shaped.

If no action is taken in Sector 2, the equipment will use the access road again for their retreat, and they will reach the beach once more by the access located in the north end of Sector 1, while the pipeline will be moved by sea with the support of the tug boat.

The wasteland on the north end of the beach, near the access channel to Marina Bay, or the beach area in Sector 1, could be used as area for temporary facilities for assembling the pipeline and putting it to sea.

The sand filling works will begin by Sector 4 moving forward always from NW to SE, respecting the limits (Table 26), calculated densities and sand volumes (Table 30) for each of the filling areas (Plans 6A).

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 means on land will position the pipe at the corresponding point, raising it from 2 m to 3 m above ground level (Photo 19). The construction or not of horseshoe dykes around the discharge point contributes to the management of densities and must be assessed in each case by the representatives of the executing agency and the designer in the area of action.

Photo 19: Backhoe placing pipe end at discharge point.

Once the dredger is connected to the pipe, it starts pumping water to clean the line, and later, the mixture of sand and water (Photo 20). During the discharge, the mechanical equipment will remain ready to operate in case their intervention is required to contribute to the drainage of the water from the discharged mixture, towards the sea. This is particularly necessary if a dredger with larger hopper capacity is used.

Photo 20: Sand discharge.

After each discharge, the mechanical equipment on land will shape the profile according to the proposed design (Photo 21) and will position the end of the pipe at the next discharge point. The height of the main elements of the profile to shape in each beach sector are specified in Plans 7A, 7B and 7C.

Photo 21: Leveling and conformation of the beach profile by mechanical equipment.

For the control of the heights in the field, as well as that of other design parameters during the execution, and as a guarantee of the project effectiveness, the participation of representatives of the designer is essential as part of an author control.

VIII.3 Oversight of the execution.

To guarantee the quality in project execution, it is recommended hiring an expert for real-time project oversight.

The oversight of project's execution will consist of:

- ***Previous survey:*** A network of topographic profiles will be created and measured on the beach, spaced every 100 m. According to the results, if necessary, adjustments to the project will be performed, in agreement with the investor, the contractor, and the executor.
- ***Oversight of the dredging process:*** On board the dredger, the dredging process will be certified, the dredged material will be inspected, and the hopper volume will be measure, and sand samples will be taken from each load, for their later analysis in the laboratory.
- ***Oversight of the filling process:*** On the beach, the filling points will be located, guaranteeing the design densities per sector, and heights will be marked on the ground, as a guide for shaping of the design profiles.
- ***Verification of topographic levels:*** As the execution progresses, the previously defined network profiles will be measured, checking the design heights and retained volume on the beach.

VIII.4 Estimated execution time.

Assuming a carrying capacity of the dredger similar to the of example (3,300 m^3), and the distance between the selected borrow and filling areas, the amount of discharge cycles per sector was estimated, carrying an average volume of 3,000 m^3 of sand per cycle. Assuming these considerations, the execution time of the project by sector was estimated. The results of this analysis are shown in Table 36.

Table 36: Estimated execution time per sector, assuming 5kn as the dredger average transfer speed and an average volume of 3,000 m^3 per trip.

Sector	Distance to the Borrow Area (km)	Volume per Charge (m^3)	Volume per Sector (m^3)	Total Cycles	Time per Cycle (h)			Execution Time (Días)
					Charge	Navigation	Discharge	
Sector 4	1.55	3000	*30000*	*10*	2.5	0.3	1.5	*1.8*
Sector 3			*20000*	*7*				*1.2*
Sector 2			*34100*	*11*				*2.1*
Sector 1			*50000*	*17*				*3.0*

To estimate the execution time, it was taken into consideration the dredger's mean navigation speed of 5 kn; meanwhile, the charge and discharge time was estimated based on experience in previous projects.

The estimated time for the execution of sand fill is equivalent to 9 days, to which should be added the days required for mobilization and assembly (7), final reshaping of the beach (3), disassembly and demobilization (7), for an estimated total of 26 days.

It was also considered that work should be carried out continuously 24 hours a day. Particularly during nighttime hours there is a drop in the wind that will favor faster progress of the work.

In addition, the timing of the project should be selected to minimize stoppages due to unfavorable wave conditions, as well as the probability that the beach will be affected by strong swells before it is fully recovered. To this end, and after analyzing the behavior of the local climate, we suggest the months of December to March, outside the North Atlantic Cyclonic Season, also excluding the months of April and May, during which the wind speed intensifies slightly.

VIII.4 Evacuation of equipment in case of extreme events.

It is recommended to carry out the works conceived in this project during the period from April to November, thus avoiding possible wave generated in the open ocean, by the peripheral circulation of Migratory Continental Anticyclones that follow the cold fronts in winter. In this period, April and May are the more conducive, by not being included in the North Atlantic hurricane season.

In view of the imminent impact of some extreme event during the execution of the woks, the following provisions shall be made:

- Temporary interruption of all works at sea and on land.
- Transfer of the dredger and other vessels involved to a safe area, moving away from the site, or seeking refuge inside Saint Johns Harbor, near the sand fill area.
- Transfer of the pipelines at sea to the mainland, fixing it to the shore of the beach, or on the back road. To avoid disassembly, it may be considered if to transfer them by sea and fixed them to the shoreline in the waters of Saint Johns Harbor.
- Transfer and assurance of minor tools and equipment, in containers to be located in the area granted for the installation of temporary facilities.

- Transfer of the heavy mechanical equipment used in the works to safe areas, it could be considered the road at the back of the beach in view of events of lower magnitude.

The abovementioned recommendations are made based on the characteristics of the area where works will be executed, as well as on the experience from previous projects. However, the executor is free to accept them or not, maintaining, in any case, full responsibility for the protection of their staff and technical resources.

IX. EFECTIVENESS OF THE PROPOSED SOLUTION

As previously mentioned, Dr. Cambers' works in the monitoring of several beaches in small islands of the Eastern Caribbean Sea, allowed estimating shoreline retreat that varied between 0.27 m/year and 1.06 m/year. Specifically, in the case of Antigua and Barbuda, the estimated mean value was of 0.85 m/year (Table 1), based on the monitoring of 30 points on different beaches, of which 24 registered erosion in the period 1992-1994.

More recently, James (2017) estimated an annual shoreline retreat of 1.134 m in Runaway Bay Beach, between 2009 and 2015.

Assuming that the mean annual trends in beach width loss will remain with values similar to those presented in the latter report, it is possible to calculate the time that it would take to lose the entire beach width achieved. The results of such estimations are shown in Table 37.

Table 37: Estimation of the time required to lose 50% or the total sand volume.

Runaway Bay Beach	Sand Fill Volume (m^3)	Beach Width Achieved (m)	Anual Td (m/year)	Loss 50% of the Width Achieved (Years)	Loss 100% of the Width Achieved (Years)
Sector 1	50000	30	-1.134	*13.2*	*26.5*
Sector 2	34100	30	-1.134	*13.2*	*26.5*
Sector 3	20000	30	-1.134	*13.2*	*26.5*
Sector 4	30000	25	-1.134	*11.0*	*22.0*

However, beaches constitute very dynamic elements, and about this is a coastal area vulnerable to the impact of storm waves generated by powerful hurricanes, question that brings uncertainty to the abovementioned estimation of project effectiveness. Therefore, it is essential to implement a management strategy that includes regular monitoring of the beach, and the design and readjustment of management strategies based on its results.

IX.1 Pre-design of Runaway Bay Beach Monitoring.

Monitoring constitutes an essential element among the guidelines of the strategy to be implemented for the management of Runaway Bay Beach in the medium and long term.

It allows gathering information on the morphodynamic evolution of the beach, contributing to the identification of the causes of erosion and the optimal selection of solution alternatives.

Once the proposed actions have been carried out, and the management strategy implemented, monitoring becomes the tool capable of verifying its effectiveness and correcting or perfecting its design.

Given the defined dimensions and sectorization, the implementation of a Morphodynamic Evolution Monitoring Program for Runaway Bay Beach is proposed, based on the formation from a network of 6 profiles.

The location of the profiles to be monitored will preferably coincide with the segments that served as a guide to obtain the cross sections shown in Plans 2A, 2B, and 2C, which in turn were used as the basis for the conception of the design profiles shown on Plans 7A, 7B, and 7C (Table 38).

Table 38: Coordinates of the ends of the segments used to obtain the cross sections of the beach, which were the basis for the conception of the design profiles.

Profile	End on Land				End at Sea			
	Antigua 1943 (BWIG)		WGS 84		Antigua 1943 (BWIG)		WGS 84	
	X	Y	Lat	Long	X	Y	Lat	Long
1A	415306.697	1895058.772	17.142431	-61.858257	415002.378	1895252.137	17.144181	-61.861117
1B	415484.060	1895301.833	17.144627	-61.856588	415010.719	1895583.966	17.147181	-61.861037
1C	415561.920	1895527.554	17.146667	-61.855854	415074.952	1895812.965	17.149251	-61.860431
2	415717.347	1895659.822	17.147862	-61.854392	415094.587	1896017.857	17.151103	-61.860245
3	415821.576	1895842.009	17.149508	-61.853410	415059.274	1896141.826	17.152224	-61.860576
4	415906.069	1896087.861	17.151730	-61.852614	415046.032	1896157.322	17.152364	-61.860701

Below are some aspects proposed for the monitoring design:

Beach: Runaway Bay. Antigua.

Variables: Sand volume (m^3/m).

Width of the sun strip (m).

Retreat of the active scarp (m).

Mean size of the sand grain (mm).

Topographic eq.: Topographic Total Station (Example: Photo 1).

Laboratory eq.: Oven and ceramic capsules for drying sand samples.

High precision digital scale.

Electronic sieve shaker.

	Set of sieves according to Wentworth classification.
	Dissecting microscope (or Stereoscope).
Desk eq.:	Computers.
Surveys:	Topographic profiles (6).
	Coastline position.
	Sedimentological sampling (one sample per profile, on the foreshore).
Frequency:	Monthly or Quarterly.
Others:	Gathering complementary information regarding the behavior of wind and wave, as well as the different meteorological factors, with an incidence on the Runaway Bay Beach, especially on the days when the field surveys are carried out, and in general throughout the monitoring period.
Outcomes:	Fundamental statistics for the characterization of beach dynamics and evolution of the measured variables, their seasonal and interannual behavior, and their trends.
	Estimation of the carrying capacity of the beach.
	Correlative analyzes between the measured variables and the behavior of modeling agents of the coastal zone, according to available information.

First of all, it is recommended the landmarking of profile starting points on land, assigning to each landmark coordinates referred to the BWIG Antigua 1943 system.

The profiles will be selected so that they are representative of the beach sector in which they are located, and allow the measurement of its main morphological elements.

The survey of topographic profiles will be carried out starting from the landmarks with assigned coordinates and going seaward, advancing in each measurement, linearly, with the same previously defined azimuth, with respect to the geographic north.

Coastline position will be determined based on the survey of the inflection point in the beach profile along the entire coastline.

The sand volume will be calculated as the area under the curve of the measured topographic profile, hence the measurement unit is m^3 per linear meter of beach (m^3/m).

The sun strip width is the distance from the seaward foot of the dune closest to the sea to the inflection point.

The carrying capacity of the beach is calculated assuming an area of 10 m^2 per bather.

Sections III.1.2 and III.2 describe the methods and software to be used for the collection and processing of field information in the topographic surveys carried out here, which will be useful for the implementation of monitoring.

Sampling of sandy sediments will be conducted in the foreshore. Sediments will be taken to the laboratory for drying, sifting, and statistical processing, for which Gradistat statistical software, built on Excel platform, is recommended.

Section III.3 refers to the methods for laboratory analysis of sand samples.

Variations in sand volume and sun strip width will be calculated based on their differences with the previous measurement, as well as with respect to the mean value of the first stage, once the first year of work has elapsed.

Graphs of topographic profiles and of the values of measured variables will be obtained. These will allow the calculation of monthly, quarterly and interannual trends, as corresponds.

For the analysis of the time series obtained from the monitoring, the use of non-parametric statistical hypothesis tests such as those of Mann-Kendall (1975) and Pettitt (1979) is recommended. After demonstrating the possibility of adjusting the series to a normal distribution, the test of Chow (1960) can provide relevant information in the analysis of changes in trends from certain events of interest.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

X. ENVIRONMENTAL CONSIDERATION

The preliminary environmental impact assessment that would generate the proposed solution, in a short term, took into consideration the possible environmental, sociocultural and economic impacts, both positive and negative, expected for the phases of preparation-execution, operation and eventual abandonment of the work (the last concept is assumed as the non-implementation of an integrated management program for the beach).

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

Tables 39 and 40 summarize the forecasts to this regard.

Among the actions proposed for beach recovery in the short term, the main effects on the environment are derived from dredging. The ICES Guidelines for the Management of Marine Sediment Extraction (2005) emphatically warn that carrying out marine sand mining inadequately can originate a significant damage to the marine and coastal environment. The importance and extension of environmental impacts will depend on numerous factors, among which stand out

- Location of the borrow area: The design of project foresaw the selection of an area situated beyond closure depth of the active profile, so that the dredging and sand filling, becomes an artificial input of sediments to the beach, without there being any hazard that the dredging enhances its erosion.
- Nature of the sediments: These are biogenic sediments in whose composition predominate the skeletal remains of Halimeda algae, in the entire column until 1.65 m. The surroundings of the defined borrow area are populated by Halimeda algae, which shows that this is a wide area of sediment production that will facilitate the gradual recovery of dredged volume, and of the locally affected populations.
- Design, method, amount and intensity of mining works: This is a sole mining action, within a period that will not extend for more than 10 days, and on a relatively small area, so that the foreseeable impacts are very localized in space and time.

Table 39: Environmental considerations.

ENVIRONMENTAL CONSIDERATIONS				
Phase	**Positive Impacts**	**Negative Impacts**	**Attenuating Elements**	**Mitigation Measures**
Preparation and Execution	Recovery of the beach's natural conditions. Recovery or enhancement of coastal dunes. Removal of invasive plant species and reforestation of the dune. Removal of hard structures that enable rip currents or interrupt the coastal transport.	Suspension of fine sediments during the dredging. Damage to populations of macroalgae and mollusks in the dredging area. Greenhouse gas emissions as a result of combustion. Risk of micro-spills of petroleum, oil, etc., due to the use of machinery. Pollution by noise.	The negative impacts will be limited to the dredging area, being punctual in space and time. The borrow area, and its surroundings do not have high biodiversity values. It was verified that the local populations show high resistance to water turbidity. The recovery affected populations in the borrow area should be expected in a short and medium term.	Negative impacts can be minimized by demanding the compliance with the technical standards established for the equipment to use. Include the monitoring of the recovery of the borrow area, as part of the beach management strategy.
Operation	Appropriate dynamic functioning of the beach. Increased capacity of resilience of the beach in view of the impact of powerful storm waves.	-	-	Implement an Integrated Management Program for Runaway Bay Beach, with emphasis on the monitoring, execution and readjustment of strategies in a medium and long term.
Eventual Abandonment (No management in the medium and long term)	-	Gradual advance of erosion process. Eventual return to conditions similar those existing before of the execution of project.	The foreseeable negatives impacts are limited only to the deterioration caused due to project execution, as a result of the absence of management in a medium and long term.	The Management Program must be transcendent in time and could serve as a model for its extension all the coasts and beaches in the country.

Table 40: Socioeconomic considerations.

SOCIO-ECONOMIC CONSIDERATIONS				
Phase	**Positive Impacts**	**Negative Impacts**	**Attenuating Elements**	**Mitigation Measures**
Preparation and Execution	Generation of jobs.	Minimum risk for the health of the workers on site, by noise or gas emission. Risks to the safety of workers due to the use of heavy machinery.	-	Requirement of compliance with suitable protection measures and standards.
Operation	Benefits from the beach as coastal defense work, protecting buildings and properties. Benefits from the beach as a natural for recreation and tourism. Appreciation of properties in the beach zone. Creation of favorable environment for the development of small businesses in tourist service, gastronomic, etc.	**Observation:** The improvement of the beach conditions could lead to an intensive use and generate impacts on the dunes and vegetation, as well as possible hot spots of pollution by solids waste.	-	Implement an Integrated Management Program for Runaway Bay Beach, with an emphasis also on the protection of the dune and its vegetation, creation of access pathways, dissemination, waste management, and distribution of services. Evaluate options to collect taxes for the exploitation of the beach, to ensure the sustainability of the Management Program.
Eventual Abandonment (No management in the medium and long term)	-	Gradual advance of erosion Possible loss of values added to the beach. Increase in the vulnerability of the coastal zone and properties located in it.	The foreseeable negatives impacts are only limited to the deterioration caused by the execution of the project due to the absence of management in a 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.

- Sensitivity of habitats and biological diversity, as well as of fisheries and other uses of the area: In spite of the high water turbidity present in the borrow area, limited incidence of sunlight on the seabed, Halimeda populations were healthy, thus being evident that they have been capable of adapting to these conditions, which would punctually increase during the dredging process. Therefore, no considerable damage is expected for this reason. The selected area does not have great biodiversity and is far from reefs zones.

The identification of the expected positive and negative impacts of the project makes it possible to recommend its execution. However, it was considered useful to deepen the matter, and advance in a preliminary Environmental Impact Assessment, through the application of RIAM method (Rapid Impact Assessment Matrix).

X.1 Preliminary Environmental Impact Assessment.

A preliminary impact assessment matrix was built to assess the Environmental Impact derived from the implementation of the actions proposed in Table 18, for its execution in the short and medium term. This simple method is known as RIAM (Rapid Impact Assessment Matrix), and consists of the following steps:

- Identification of impacts.
- Classification by Physical-Chemical, Biological-Ecological, Socio-Cultural, or Economic-Operational components.
- Assessment 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 assessment of the criteria is carried out according to the scale shown in Table 41.

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

$$ES = (A_1 x A_2) x (B_1 + B_2 + B_3)$$

Meanwhile, the ranking by ranges is done based on the scale shown in the Table 42.

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

Table 41: 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.	Permanence (B1)	1	=	No Changes / Does not apply
		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

Table 42: 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, the effect of which would extend indefinitely in the event of making the decision of taking No Action, 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.

In 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 (Decision Not to Act).
- 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 39 and 40, the list of impacts was adjusted to the criteria of RIAM method, for the different stages and components (Tables 43 and 44).

Tables No. 45 to 48 list and weigh the evaluated impacts, highlighting the stage to which they correspond.

From this analysis, the matrices corresponding to the current situation and each of the stages analyzed (Tables 49 to 52), as well as their graphic outputs (Fig. 55 to 58), were obtained.

During the application of RIAM methodology, a total of 40 environmental impacts could be identified. From them:

- By components: Physical-Chemical 13; Biological-Ecological 8; Socio-Cultural 10; and Economic-Operational 9.
- Negative impacts: 24. However, 13 of them are typical of the current condition, being present as long as no action is taken; meanwhile, after the execution of the proposed actions in the short term, 11 of them could be expressed 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 striking. These are impacts that are achieved through the Execution of the proposed actions in the short term and last in the medium and long term, requiring a Management Program to guarantee their preservation.

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

Table 43: List of identified environmental impacts. Physical-Chemical and Biological-Ecological Components. The impacts derived from not acting are highlighted; as well as not implementing or abandoning the management program in the long term.

No.	Nature of the Impact	Stage	Action	Activity	Environmental impact	Character	Assessment	Permanence, Reversibility and Accumulation	Observation
1	PHYSICAL - CHEMICAL	CURRENT	No Action	Insufficient Water Circulation	Hardening of the bottom in the bathing area in Sector 2	Negative	Low	Permanent, Reversible and Cumulative	With No Action, Permanent and Cumulative. With Action, Reversible.
2		CURRENT - ABANDONMENT	No Action - Non-Implementation of Management	Erosive process	Gradual shoreline retreat	Negative	Moderate		
3					Loss of beach resilience capacity	Negative	Moderate		
4		EXECUTION	Artificial Beach Nourishment (ABN)	Extraction	Alteration of the terrain in the borrow area	Neutral	Neutral	Temporary and Reversible	No practical effects. Naturally reversible.
5					Increased water turbidity in the borrow area	Negative	Low	Temporary, Reversible and Non-cumulative	Highly turbid waters with healthy (adapted) algae.
6					Damage to areas of natural sand production	Negative	Low		Damage limited to the borrow area, in an extensive production
7				All tasks	Risk of hydrocarbon micro-spills	Negative	Very low		Avoidable with good technological practices.
8				Discharge	Increased turbidity in beach water	Negative	Low		Very little transcendent in time. Zone without benthic life.
9				All tasks	Pollution by emission of combustion gases	Negative	Very low	Temporary and Non-cumulative	Very limited effect.
10				Extraction	Noise pollution	Negative	Very low		
11		EXEC - 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.
12					Increased beach resilience capacity	Positive	High	Temporary, Reversible and Non-cumulative	
13		EXEC - OPER - ABAND	CA	Demolition	Removal of anthropogenic erosive agents (structures)	Positive	High	Permanent and Irreversible	Irreversible specifically in terms of structures.
14	BIOLOGICAL - ECOLOGICAL	CURRENT	No Action	Insufficient Water Circulation	Water eutrophication by confinement in Sector 2	Negative	Low	Permanent, Reversible and Cumulative	With No Action, Permanent and Cumulative. With Action, Reversible.
15		CURRENT - ABANDONMENT	No Action - Non-Implementation of Management	Colonization of Invasive Plants	Damage to the ecosystem due to colonization of invasive plants	Negative	Moderate		
16				Erosive process	Impact on vegetation due to erosion	Negative	Low		
17		EXECUTION	Artificial Beach Nourishment (ABN)	Mining	Damage to biodiversity in the borrow area	Negative	Low	Temporary, Reversible and Non-cumulative	Limited borrow area damage. Resilient ecosystem.
18				Mining - Discharge	Slight increase in nutrients in borrow area and beach	Negative	Low		Very low impact on water quality, very limited in time.
19		EXEC - OPERATION	CA	Invasive Plant Control	Elimination of invasive plants on the dune	Positive	Moderate	Temporary and Reversible	Reversible without management in the medium and long term.
20			CA	Dune Reforestation	Rehabilitation of coastal vegetation	Positive	Moderate		
21			ABN and CA	Discharge - Profiling - Other tasks	Beach rehabilitated as a protective barrier for the ecosystem	Positive	Moderate		

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

Table 44: List of identified environmental impacts. Sociological-Cultural and Economic-Operational Components. The impacts derived from not acting are highlighted; as well as not implementing or abandoning the long-term management program.

No.	Nature of the Impact	Stage	Action	Activity	Environmental impact	Character	Assessment	Permanence, Reversibility and Accumulation	Observation
22	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.
23					Damage to buildings in the coastal zone	Negative	Low		
24					Loss of beach natural aesthetic values	Negative	Moderate		
25		EXECUTION	ABN and Complementary Actions (CA)	All tasks	Employment generation during execution	Positive	Very low	Temporary	During execution
26					Risk to the health of workers due to contaminants	Negative	Very low		
27					Safety risk of workers due to the use of machinery	Negative	Very low		
28		EXEC - OPERATION		Discharge - Profiling - Other tasks	Recovery of beach tourist and recreational use value	Positive	High	Temporary, Reversible and Non-cumulative	Reversible without appropriate Management Program.
29					Beach as coastal defense for building protection	Positive	High		
30					Beach aesthetic-environmental improvement	Positive	High		
31		OPERATION	Use and Management	Management Program	Generation of employment during Management	Positive	Very low	Temporary	Management Program
32	ECONOMIC - OPERATIONAL	CURRENT - ABANDONMENT	No Action - Non-Implementation of Management	Erosive process	Impact on beach tourist potential	Negative	Very high	Permanent, Reversible and Cumulative	With No Action, Permanent and Cumulative. With Action, Reversible.
33					Depreciation of properties in the beach area	Negative	Moderate		
34					Unfavorable environment for tourism-related services	Negative	Moderate		
35					Increased cost of infrastructure maintenance	Negative	Moderate		
36		EXECUTION	ABN and Complementary Actions (CA)	Investment	High cost of investment	Negative	High	Permanent and Reversible	High initial investment. Sustainable income management.
37		EXEC - OPERATION		Discharge - Profiling - Other tasks	Increase in beach tourist potential	Positive	High	Temporary, Reversible and Non-cumulative	Reversible without appropriate Management Program.
38					Appraisal of properties in the beach area	Positive	Moderate		
39					Creation of a favorable environment for tourism-related services	Positive	Moderate		
40					Reduction of infrastructure maintenance costs	Positive	Moderate		

Table 45: Physical-Chemical Component. Assessment of impacts by stage.

Code	Physical-Chemical Component	Score				Classification				ASSESSMENT				
		Ac.	Ex.	Op.	Ab.	Ac.	Ex.	Op.	Ab.	A1	A2	B1	B2	B3
PC1	Hardening of the bottom in the bathing area in Sector 2	-16				-B				1	-2	3	2	3
PC2	Gradual shoreline retreat	-32			-32	-C			-C	2	-2	3	2	3
PC3	Loss of beach resilience capacity	-32			-32	-C			-C	2	-2	3	2	3
PC4	Alteration of the terrain in the borrow area		0				N			1	0	2	2	1
PC5	Increased water turbidity in the borrow area		-12				-B			2	-1	2	2	2
PC6	Damage to areas of natural sand production		-18				-B			1	-3	2	2	2
PC7	Risk of hydrocarbon micro-spills		-6				-A			1	-1	2	2	2
PC8	Increased turbidity in beach water		-12				-B			2	-1	2	2	2
PC9	Pollution by emission of combustion gases		-5				-A			1	-1	2	1	2
PC10	Noise pollution		-5				-A			1	-1	2	1	2
PC11	Recovery of natural beach conditions		30	30			C	C		2	3	2	2	1
PC12	Increased beach resilience capacity		36	36			D	D		2	3	2	2	2
PC13	Removal of anthropogenic erosive agents (structures)		42	42	42		D	D	D	2	3	3	3	1

Table 46: Biological-Ecological Component. Assessment of impacts by stage.

Code	Biological-Ecological Component	Score				Classification				ASSESSMENT				
		Ac.	Ex.	Op.	Ab.	Ac.	Ex.	Op.	Ab.	A1	A2	B1	B2	B3
BE1	Eutrophication of water by confinement in Sector 2	-16				-B				1	-2	3	2	3
BE2	Damage to the ecosystem due to colonization of invasive plants	-32			-32	-C			-C	2	-2	3	2	3
BE3	Impacts on vegetation due to erosion	-16			-16	-B			-B	2	-1	3	2	3
BE4	Damage to biodiversity in borrow area		-12				-B			1	-2	2	2	2
BE5	Slight increase in nutrients in borrow area and beach		-12				-B			2	-1	2	2	2
BE6	Removal of invasive plants on the dune		20	20			C	C		2	2	2	2	1
BE7	Rehabilitation of coastal vegetation		30	30			C	C		2	3	2	2	1
BE8	Beach rehabilitated as a protective barrier for the ecosystem		30	30			C	C		2	3	2	2	1

Table 47: Socio-Cultural Component. Assessment of impacts by stage.

Code	Socio-Cultural Component	Score				Classification				ASSESSMENT				
		Ac.	Ex.	Op.	Ab.	Ac.	Ex.	Op.	Ab.	A1	A2	B1	B2	B3
SC1	Loss of beach tourist and recreational use value	-72			-72	-E			-E	3	-3	3	2	3
SC2	Damage to buildings in the coastal zone	-16			-16	-B			-B	1	-2	3	2	3
SC3	Loss of beach natural aesthetic values	-32			-32	-C			-C	2	-2	3	2	3
SC4	Employment generation during execution		8				A			1	2	2	1	1
SC5	Risk to the health of workers due to contaminants		-4				-A			1	-1	2	1	1
SC6	Safety risk of workers due to the use of machinery		-8				-A			1	-2	2	1	1
SC7	Recovery of beach tourist and recreational use value		54	54			D	D		3	3	2	2	2
SC8	Beach as coastal defense for construction protection		36	36			D	D		2	3	2	2	2
SC9	Beach aesthetic-environmental improvement		36	36			D	D		2	3	2	2	2
SC10	Generation of employment during Management			8				A		1	2	2	1	1

Table 48: Economic-Operational Component. Assessment of impacts by stage.

Code	Economic-Operational Component	Score				Classification				ASSESSMENT				
		Ac.	Ex.	Op.	Ab.	Ac.	Ex.	Op.	Ab.	A1	A2	B1	B2	B3
EO1	Impact on beach tourist potential	-72			-72	-E			-E	3	-3	3	2	3
EO2	Depreciation of properties in the beach area	-32			-32	-C			-C	2	-2	3	2	3
EO3	Unfavorable environment for tourism-related services	-32			-32	-C			-C	2	-2	3	2	3
EO4	Increased cost of infrastructure maintenance	-32			-32	-C			-C	2	-2	3	2	3
EO5	High cost of investment		-54				-D			3	-3	3	2	1
EO6	Increased beach tourist potential		54	54			D	D		3	3	2	2	2
EO7	Appraisal of properties in the beach area		24	24			C	C		2	2	2	2	2
EO8	Creation of a favorable environment for tourism-related services		24	24			C	C		2	2	2	2	2
EO9	Reduction of infrastructure maintenance costs		24	24			C	C		2	2	2	2	2

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

An analysis per stage is required.

Current Situation (No Action Option)

The option of not acting leads to 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 erosion process (Table 49 and Fig. 55).

Class E classifies the Loss of tourist and recreational use value in its social component, and the Impact to the beach tourist potential, economically, both with an impact at the national level, given that this beach is one of the most extensive and historically used by the population on the island of Antigua.

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

Table 49: 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	1	0	0	0	0	0	0	0
BE	0	0	1	2	0	0	0	0	0	0	0
SC	1	0	1	1	0	0	0	0	0	0	0
EO	1	0	3	0	0	0	0	0	0	0	0
Total	**2**	**0**	**7**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

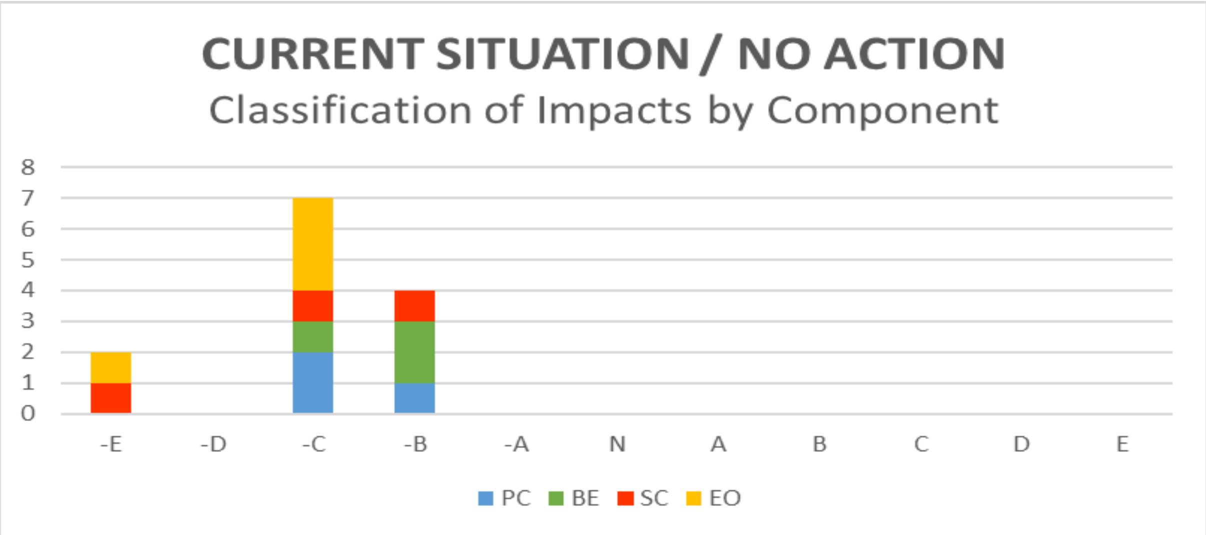


Figure 55: Graphic output of RIAM Matrix. Impacts by Class. Current Situation (No Action Option).

<u>Execution Stage</u>

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 contribute 13 positive impacts of Class C (Moderate) and D (High), an expression of the desired reversal of the current state of the beach (Table 50 and Fig. 56).

In contrast, the foreseeable negative impacts of this type of action are generally classified as Low or Very Low (Classes A and B), several are due to small impacts avoidable through 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 50: 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	3	3	1	0	0	1	2	0
BE	0	0	0	2	0	0	0	0	3	0	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
T	**0**	**1**	**0**	**5**	**5**	**1**	**1**	**0**	**7**	**6**	**0**

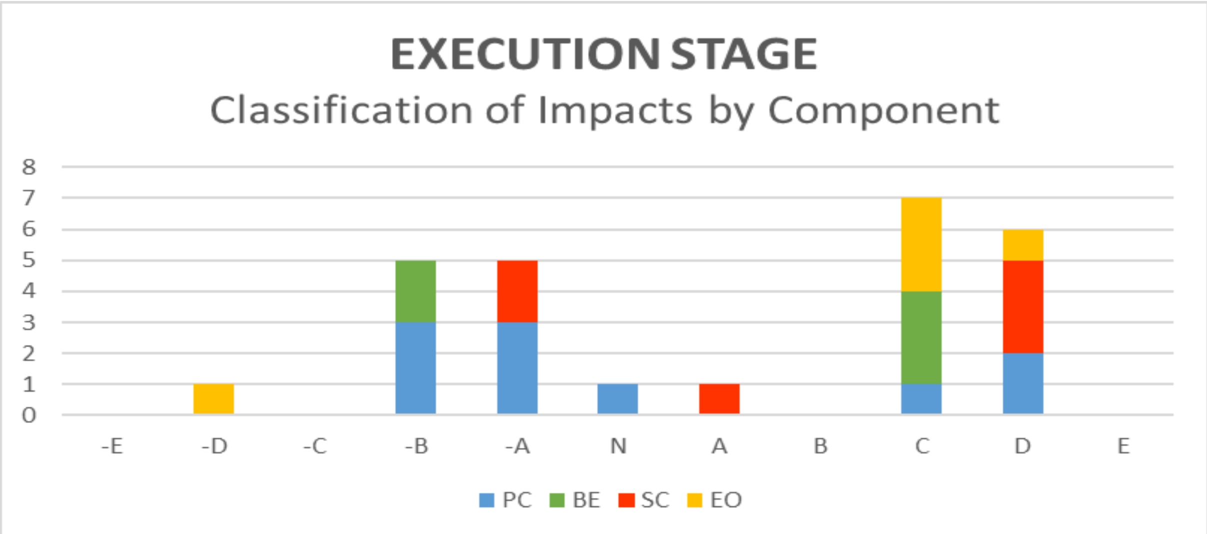


Figure 1: Graphic output of RIAM Matrix. Impacts by Class. Execution Stage.

Operation Stage (Use or Exploitation)

The objectives that will be achieved from the execution of the 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 (Table 51 and Fig. 57).

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

Table 51: Matrix of Impacts by Class. Operation Stage (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	2	0
BE	0	0	0	0	0	0	0	0	3	0	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
T	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**7**	**6**	**0**

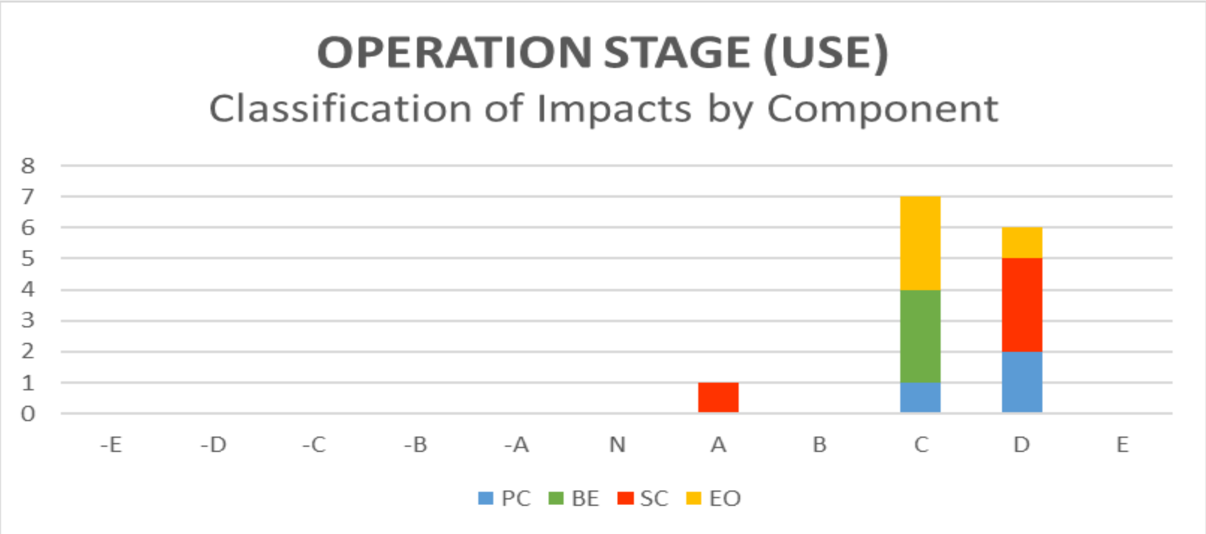


Figure 2: Graphic output of RIAM Matrix. Impacts by Class. Operation Stage (Use of the beach).

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

After 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, then continuing to deteriorate.

The benefit of the demolitions of buildings located in the coastal zone that 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 52 and Fig. 58).

Table 52: Matrix of Impacts by Class. Abandonment (Non-implementation or abandonment of the Beach Management Plan in the medium and long term).

ABANDONMENT (WITHOUT MANAGEMENT PLAN)											
Class	**-E**	**-D**	**-C**	**-B**	**-A**	**N**	**A**	**B**	**C**	**D**	**E**
PC	0	0	2	0	0	0	0	0	0	1	0
BE	0	0	1	1	0	0	0	0	0	0	0
SC	1	0	1	1	0	0	0	0	0	0	0
EO	1	0	3	0	0	0	0	0	0	0	0
T	**2**	**0**	**7**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**

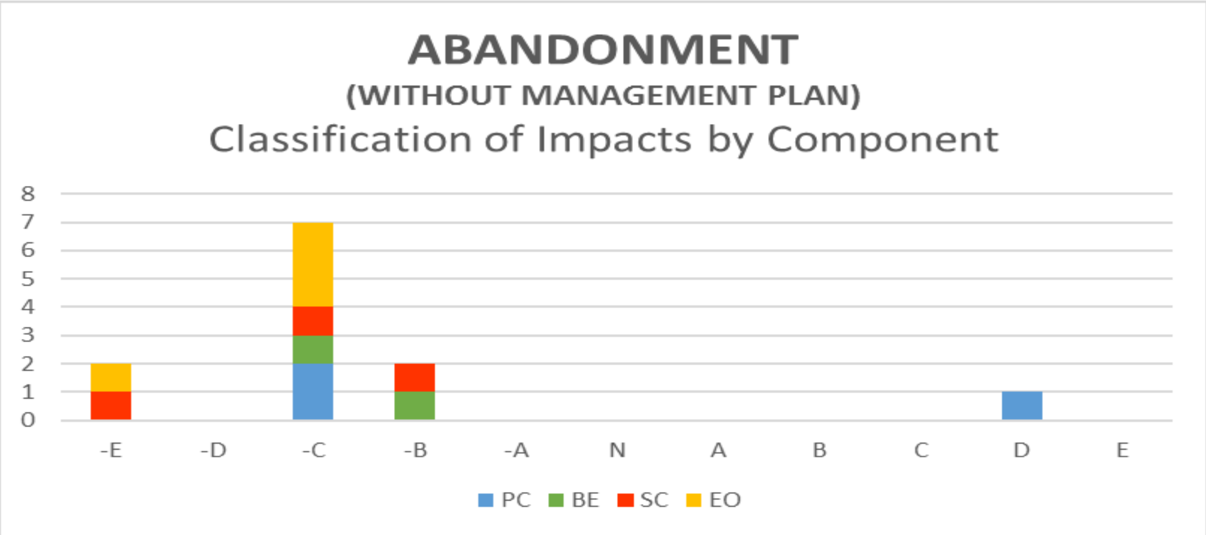


Figure 3: Graphic output of RIAM Matrix. Impacts by Class. Eventual Abandonment (Non-implementation or abandonment of the Beach Management Plan in the medium and long term).

<u>Conclusions from the application of RIAM Method</u>

From the preliminary assessment of the environmental impacts of the proposed actions for the rehabilitation of Runaway Bay 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 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 damages in all the components, and consequently, the costs of a possible new intervention for beach rehabilitation.

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

XI. ESTIMATED COST

The estimated budget for the execution of the discharge of sand on Runaway Bay Beach is shown in Table 53, and has been prepared based on experience in similar works carried out in Cuba and in the Caribbean area, for which reason the calculations are preliminary, reflecting the items that are commonly taken into account in the cost sheets prepared by the executing companies, which allows having an order of magnitude of the cost of the work. For more accurate calculations, a bidding is required.

Inversiones Gamma SA is in a position to provide technical assistance in the process of hiring, and for the oversight of works.

Table 53: Estimated cost of dredging and sand filling in Runaway Bay Beach.

ESTIMATED COSTS SHEET (RUNAWAY BAY BEACH)				
ITEM	**UNIT**	**UNIT PRICE**	**QUANTITY**	**AMOUNT**
DIRECT EXPENSES				
Dredging, filling and shaping of design profiles	USD/m^3	$10.00	134,100.00	$1,341,000.00
Dredge mobilization and demobilization (included)			30%	$402,300.00
GENERAL EXPENSES				
Profit			5%	$67,050.00
Administrative expenses			3%	$40,230.00
Insurance and sureties			2%	$26,820.00
Workers liquidation			1.5%	$20,115.00
Pension and retirement			1.5%	$20,115.00
Author supervision and control			5%	$67,050.00
Contingencies and other expenses			1%	$13,410.00
GRAND TOTAL				**$1,595,790.00**

This table was prepared based on available information regarding the cost of executing similar projects and bids presented in the region, as shown in Table 54. It should be noted that these prices fluctuate depending on the variation in the price of fuel, as well as the value of foreign currency, among other elements.

It is even more complex to determine the cost of mobilization because it will depend on where the executor has its vessels, equipment and personal located, at the time the work begins.

Tabla 1: Examples of global cost per cubic meter (m^3) of sand dumped from artificial sand nourishment projects executed in recent years in the Caribbean region. The % that represents the cost of mobilization is included, in those projects where the information is available.

Beach	Volume (m^3)	Country	Year	Movilization (% del Total)	Cost / m^3
Varadero	1,087,000	Cuba	1998		$4.59
4 Playas	1,300,000	Dominican Rep.	2006		$13.84
Cancún	2,700,000	México	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
Playa Larga	267,500	Cuba	2018		€ 9.38

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

XII. BIBLIOGRAFY

Albuquerque, K. and McElroy, J.L.: Antigua and Barbuda: A Legacy of Environmental Degradation, Policy Failure, and Coastal Decline. United States Agency for International Development. July 1995.

Automated Coastal Engineering System Manual (ACES). Coastal Engineering Research Center. Department of the Army. Waterways Experiment Station, Corps of Engineers. Vicksburg, Mississippi. 1992.

Avello, O y Pavlidis, Y.: Sedimentos de la Plataforma Cubana. Serie Oceanológica No. 30. A.C. de Cuba. 1975.

Baldwin, J.: Tourism development, wetland degradation and beach erosion in Antigua, West Indies. Department of Geography, University of Oregon. USA. 2000.

Bruun, P. (1954) “Coastal erosion and development of beach profiles”. U.S. Army Beach Erosion Board Technical Memorandum No. 44. Beach erosion board. U.S. Army Corps of Engineer, Washington DC.

CARIBSAVE, 2012: The CARIBSAVE Climate Change Risk Atlas (CCCRA). Climate Change Risks Profile for Antigua and Barbuda. UKaid. AusAID.

Coastal Engineering Manual. “Beach-fill volume required to produce specified dry beach width”. Technical note II-32. Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station. 1995.

Coastal Engineering Manual. Part III. U. S. Army Corps of Engineers. Washington, DC. 1999.

Coastal Engineering Manual (2002). Part V, “Chapter 4: Beach fill design”. U.S. Army Engineer Coastal and Hydraulic Laboratory.

Coastal Engineering Research Center (ed). Shore Protection Manual. U.S.A. 1984.

Dean, R. G. (1977). “Equilibrium beach profiles: U. S. Atlantic and Gulf Coasts”. Department of Civil Engineering. Ocean Engineering Report No. 12. University of Delaware. Newark.

Dean, R. G. (1987). “Coastal sediment processes: Toward engineering solution”. Proceedings, Specialty Conference on Coastal Sediments ’87. American Society of Civil Engineers. 1-24.

Dean, R. G. (1991). “Beach response to sea level change”. University of Florida. 1991.

Dean, R. G. (1991). “Equilibrium beach profiles: characteristics and aplications” Journal of Coastal Research 7 (1). 53-84.

Dvorstiak, J., Rossik, B., Polomsky, P., Valko, P., Adasek, S., Mihalik, F., López, A. y Armas, B. Instrucciones Técnicas de los Trabajos Topográficos. Editorial Pueblo y Educación. Cuba. 1983.

García, C., "Actuaciones para el control de la erosión en playas biogénicas. El caso de la playa de Varadero". Tesis de Doctorado. Instituto de Oceanología, 2005.

GIOC, 2000 (Universidad de Cantabria (UC), Dirección General de Costas del Ministerio de Medio Ambiente (España), Grupo de Ingeniería Oceanográfica y de Costas (GIOC): Documento de Referencia. Master en Ciencias y Tecnologías para la Gestión de la Costa.

Hallermeier, R.J. "Fall velocity of beach sands". Coastal Engineering Technical Note, CETN-II-4, Coastal Engineering Research Center. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 1981(a).

Hallermeier, R.J. "Seaward limits of significant sand transport by waves: An annual zonation for seasonal profiles". Coastal Technical Aid No. 81-2, Coastal Engineering Research Center. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 1981 (b).

IOM, 2021: Migration, Environment, Disaster and Climate Change Data in the Eastern Caribbean. Antigua and Barbuda Country Analysis. International Organization for Migration.

IPCC, 2022: Climate Change 2022. Impacts, Adaptation and Vulnerability. Summary for policymakers. World Meteorological Organization. United Nations Environment Programme. Intergovernamental Panel on Climate Change.

James, P.: Analysis of beaches changes in Antigua and Barbuda (2009-2015). Fisheries Division. Ministry of Agriculture, Lands, Fisheries and Barbudas Affairs. Antigua and Barbuda. Febrero de 2017.

Juanes, J. L. La Erosión en las Playas de Cuba. Alternativas para su Control. Tesis de Doctorado. Cuba. 1996.

Kiknadze, A. G.: El litoral cubano y los problemas con respecto a su defensa. (Informe inédito en idioma original Ruso). Inst. de Oceanología-INTUR. 1990.

Leonard, L. A., Dixon, K. L., and Pilkey, D. H.: A comparison of beach replenishment on the U.S. Atlantic, Pacific and Gulf coast. *Journal of Coastal Research,* Special Issue. (6), 127-140, 1990.

Manual on Artificial Beach Nourishment. 1987. Delft Hydraulics.

MOPU: Ministerio de Obras Públicas y Transporte de España (ed). Actuaciones en la Costa, España, 1988.

National Office of Disaster Services (NODS), 2016: Country Document for Disaster Risk Reduction: Antigua and Barbuda, 2016.

Petelín, V. M. (1967): Análisis granulométrico de los sedimentos marinos. Edit. Nauta, Moscú, pp. 76.

UNEP, 2003: Diagnóstico de los procesos de erosión en las playas arenosas del Caribe. United Nations Environment Programme. Agencia de Medio Ambiente. Cuba. Colectivo de autores. La Habana. Marzo de 2003.

UNESCO, 2000: Wise practices for coping with beach erosion. Antigua and Barbuda. Fisheries Division. Ministry of Agriculture, Lands, Fisheries and Barbudas Affairs. Antigua and Barbuda. Development Control Authority. Antigua and Barbuda. University of Puerto Rico. Sea Grant College Program. Caribbean Development Bank. 2000.

Wong, P. P. Coastal Protection Measures – Case of Small Island Developing States to Address Sea-level Rise. Asian Journal of Environment & Ecology. 6(3): 1-14, 2018; Article no. AJEE.41019. ISSN: 2456-690X.

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

XIII. LIST OF PLANS

Inversiones GAMMA S.A.

No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba

gamma@gamma.com.cu www.gamma.com.cu/en

XIV. ANNEXES

ANNEX I

Runaway Bay Beach. Results of Grain Size Analysis.

ANNEX II

Great Sister Basin. Results of Grain Size Analysis.

ANNEX III

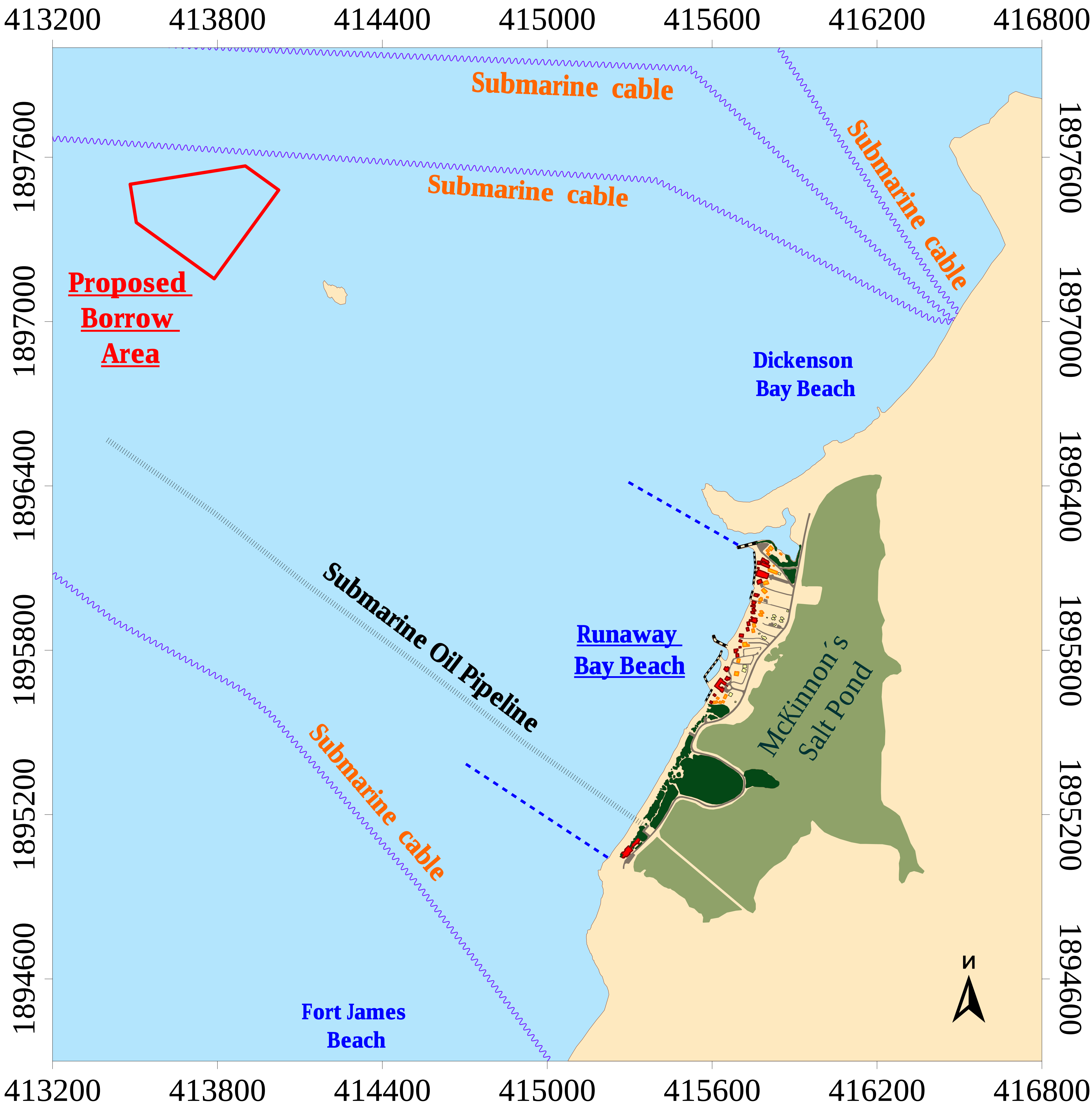
Results of Numeric Simulations. OLUCA-SP and COPLA-SP models. Wave Height and Intensity of Coastal Currents.

ANNEX IV

Results of the Numeric Simulations. EROS-SP model. Coastal Sediment Transport and Seabed Variation.

Inversiones GAMMA S.A.
No. 308, 14 Street between 3rd and 5th Ave. Miramar, Playa, Havana, Cuba
gamma@gamma.com.cu www.gamma.com.cu/en

PLANS

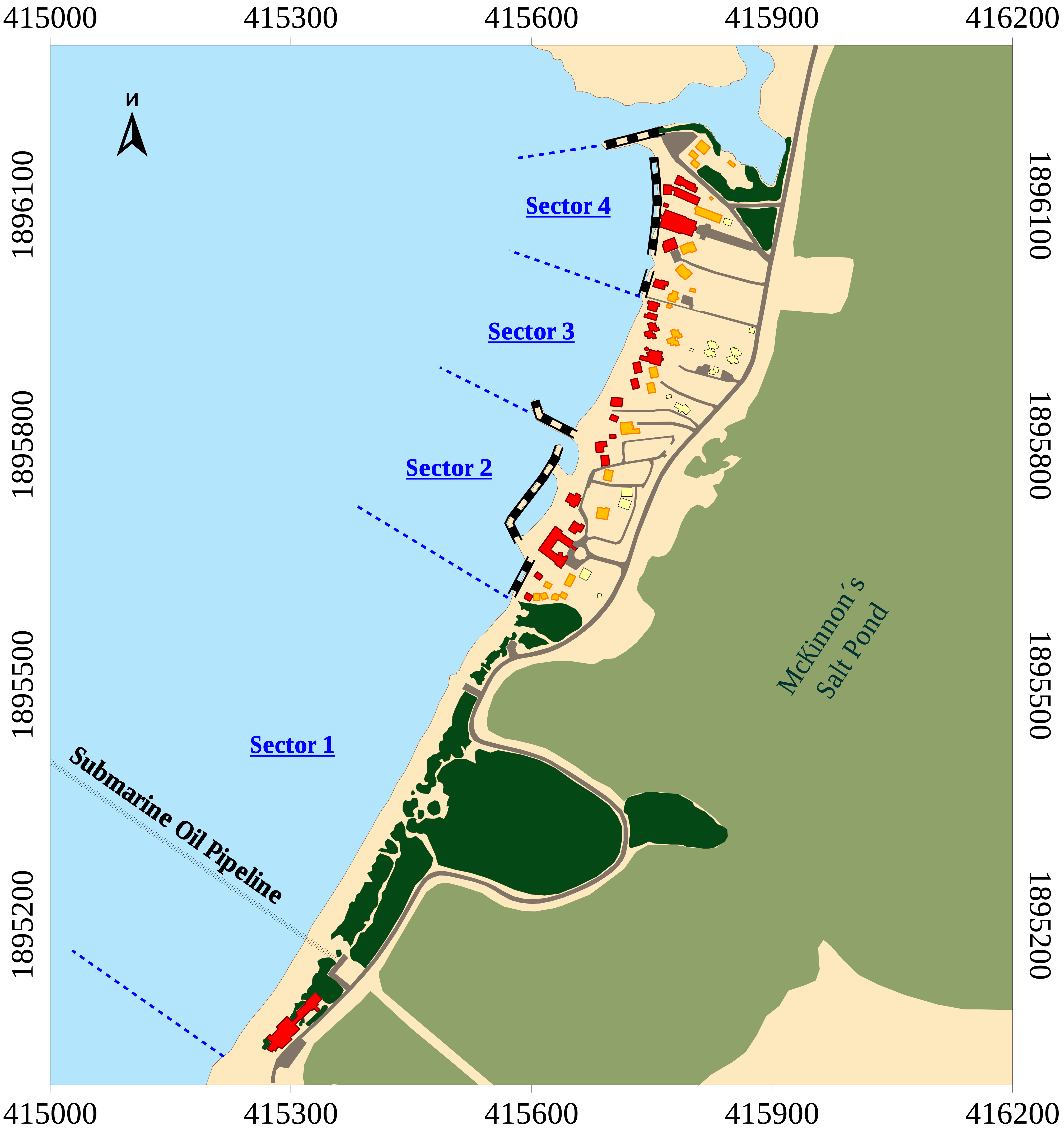


LEGEND

- Geographic North
- Proposed Borrow Area Delimitation
- Runaway Bay Beach Limits
- Submarine Cables
- Submarine Oil Pipeline
- Coastal Defense Structure
- First Line Structures
- Second Line Structures
- Third Line Structures
- Tree and Shrub Vegetation
- Main road and others.

Transverse Mercator Projection
Antigua 1943 Datum
British West Indies Grid Coordinates System

GAMMA	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** GENERAL PLAN	
DATE: June 2022	**SCALE:** 1:15 000	**PLAN:** 1



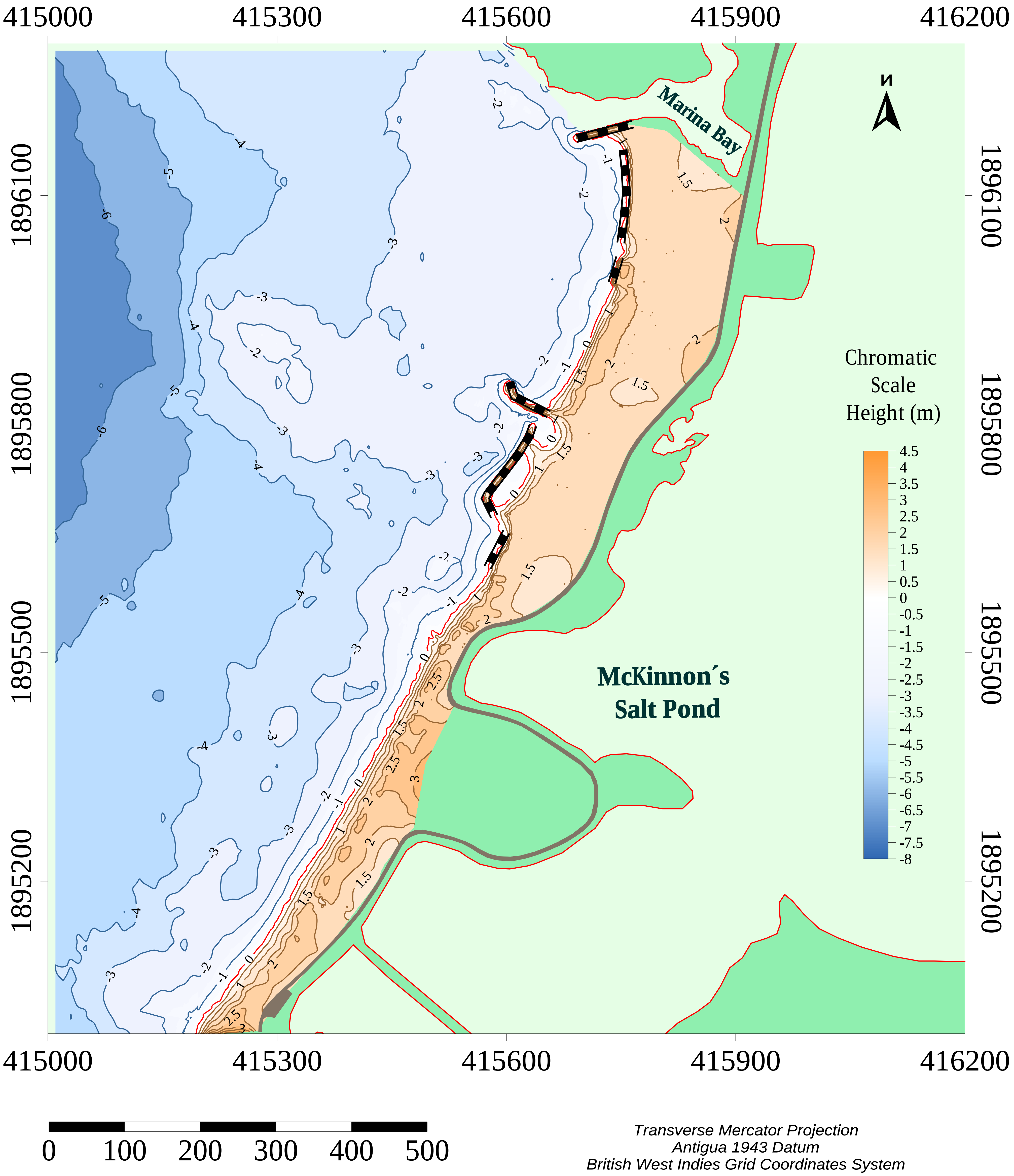
0 100 200 300 400 500

LEGEND

- Geographic North
- Sectors Limits
- Submarine Oil Pipeline
- Coastal Defense Structure
- First Line Structures
- Second Line Structures
- Third Line Structures
- Tree and Shrub Vegetation
- Main road and others.

Transverse Mercator Projection
Antigua 1943 Datum
British West Indies Grid Coordinates System

GAMMA TECNOLOGÍA Y MEDIO AMBIENTE	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach General Plan	
DATE: June 2022	**SCALE:** 1:5 000	**PLAN:** 1A



Transverse Mercator Projection
Antigua 1943 Datum
British West Indies Grid Coordinates System

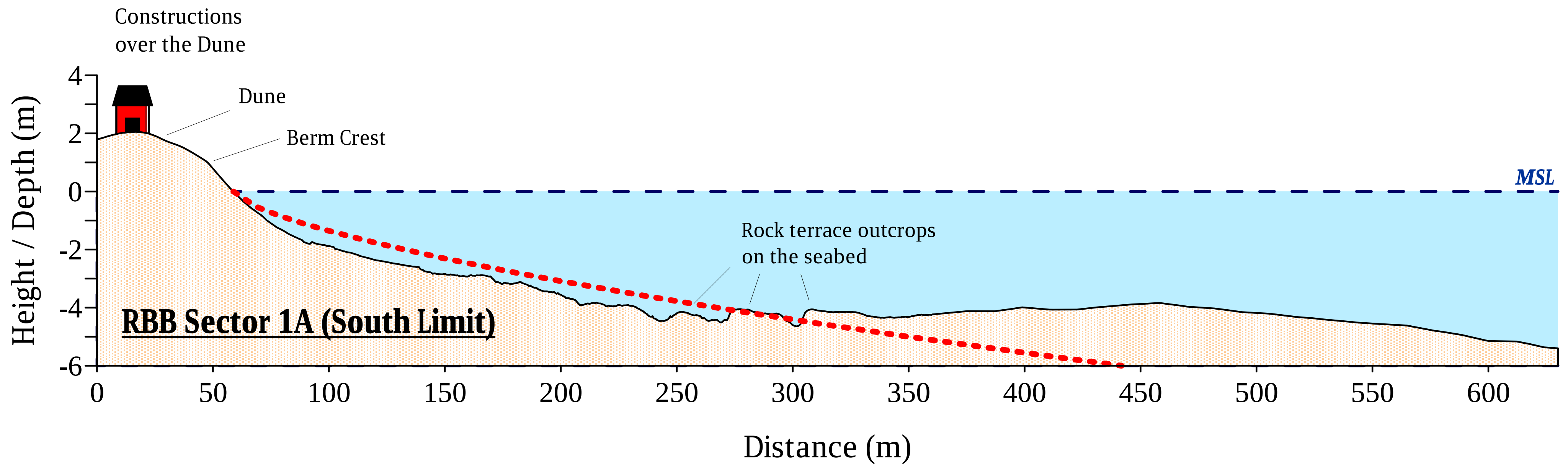
Height in meters referred to mean sea level

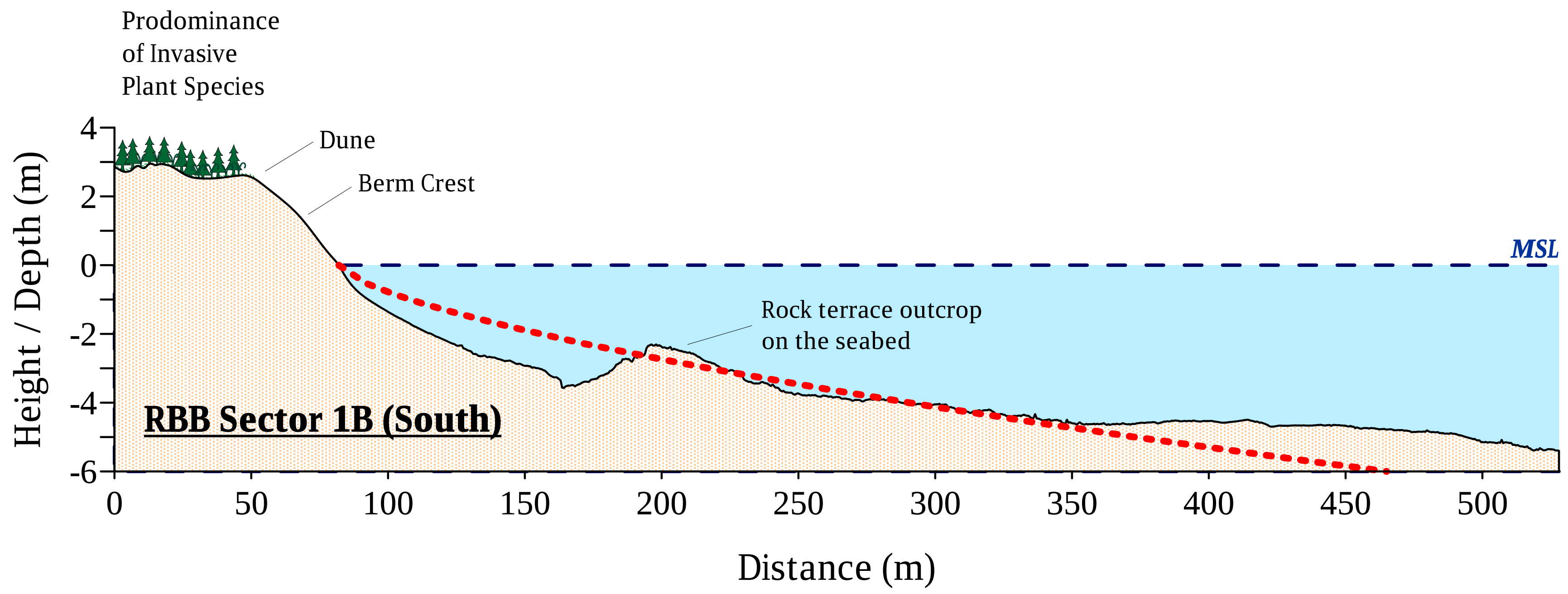
Isohypses every 0.5 m
Isobaths every 1.0 m

LEGEND

- N Geographic North
- 0 Coastal Line
- 2 Isohypses
- -2 Isobaths
- Main Road
- No Data
- Coastal Defense Structures

GAMMA TECNOLOGÍA Y MEDIO AMBIENTE	**MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA**
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.
MADE BY: BSc. Pavel Morales Díaz	
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Topographic Plan
DATE: June 2022	**SCALE:** 1:5 000 **PLAN:** 2





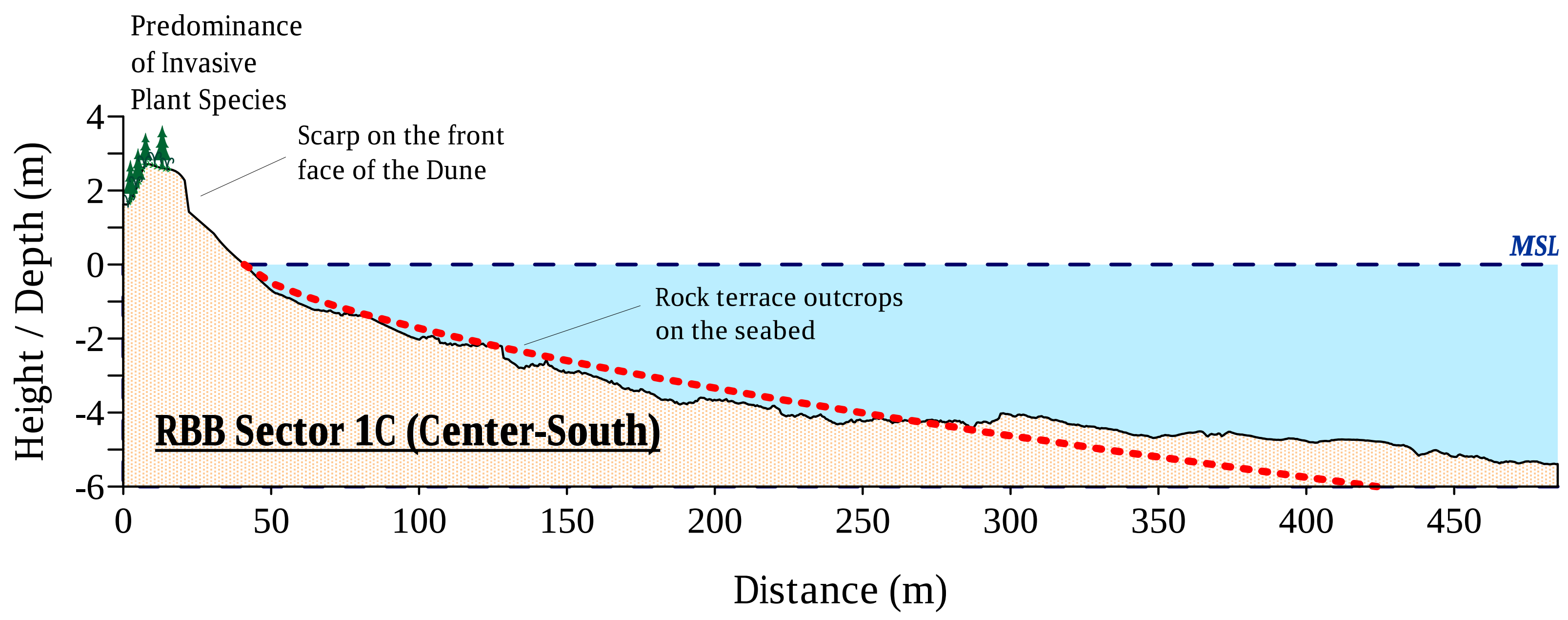
LEGEND

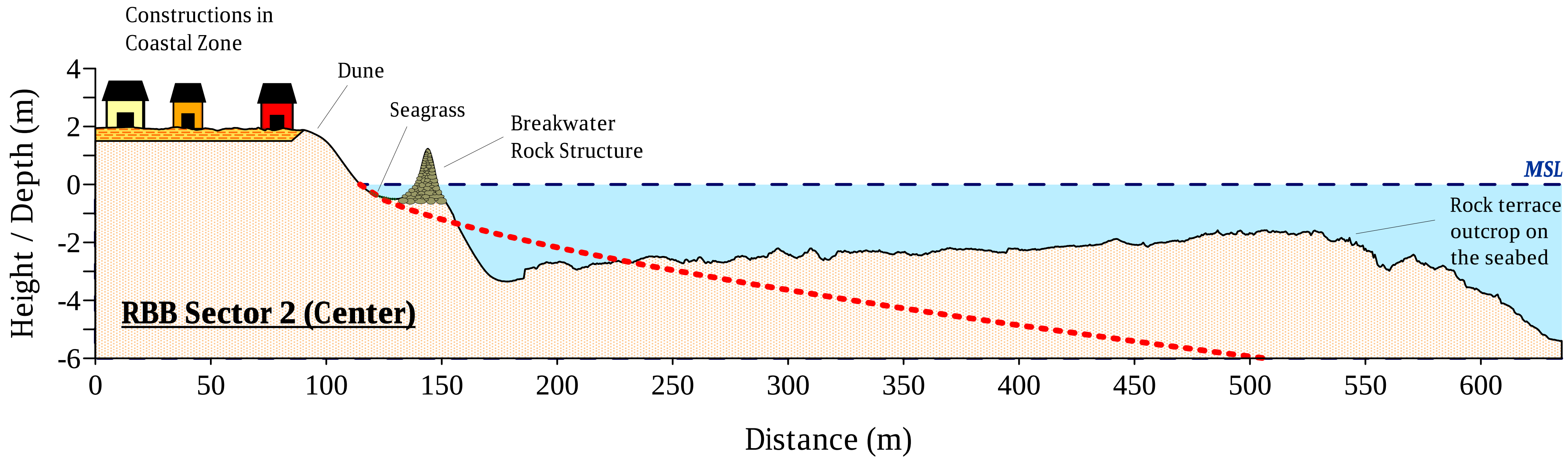
Predominance of Invasive Plant Species

First Line Structures

Equilibrium Profile

GAMMA TECNOLOGÍA Y MEDIO AMBIENTE	**MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA**
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.
MADE BY: BSc. Pavel Morales Díaz	
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Type Profiles Sector 1
DATE: June 2022	**SCALE:** X 1: 200 Y 1: 2 500 — **PLAN:** 2A

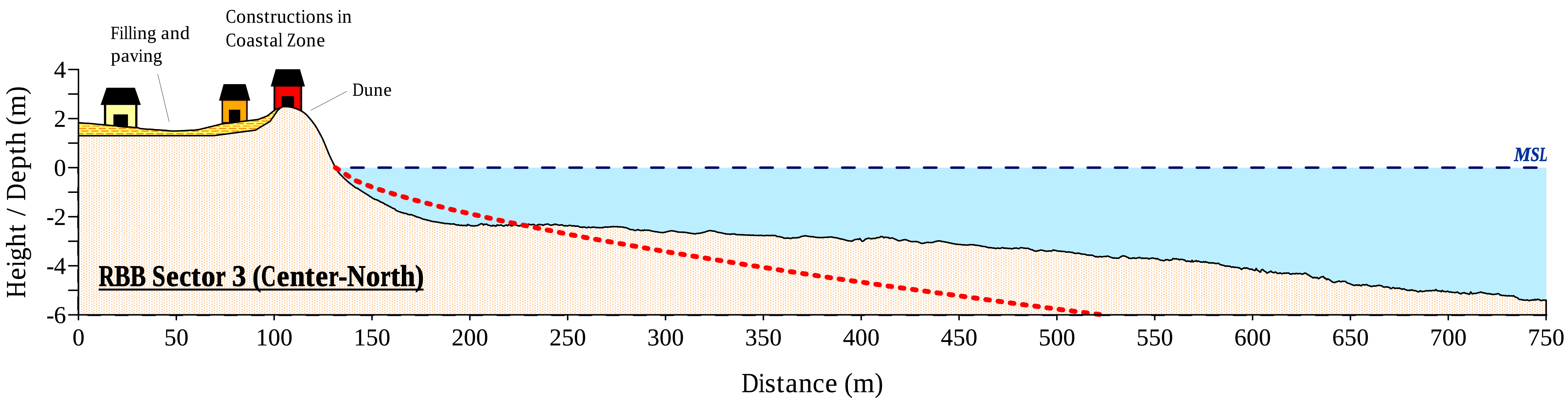


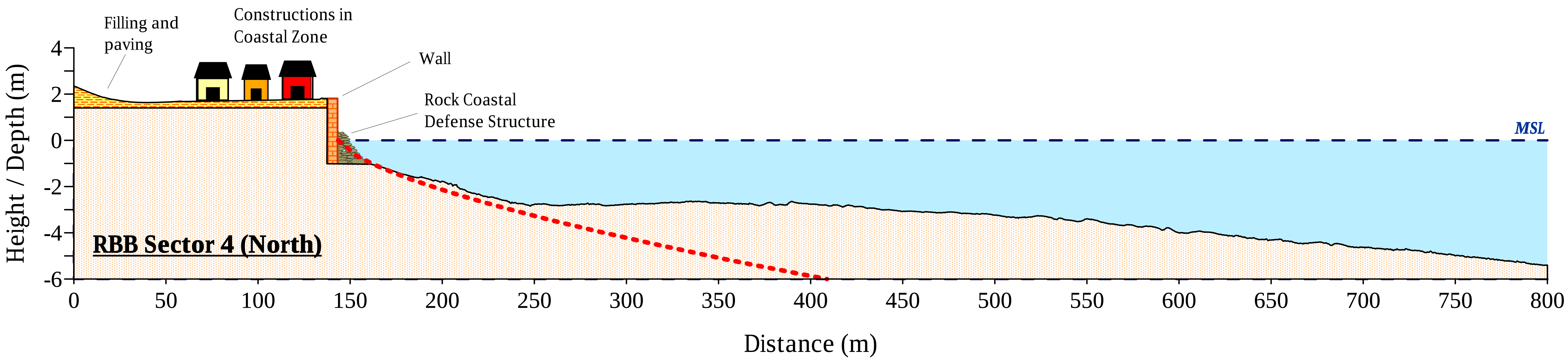


LEGEND

- Technical filling and paving areas
- Rock Coastal Defense Structure
- First Line Structures
- Second Line Structures
- Third Line Structures
- Predominance of Invasive Plant Species
- Seagrass
- Equilibrium Profile

GAMMA	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Type Profile Sectors 1(C) and 2	
DATE: June 2022	**SCALE:** X 1: 200 Y 1: 2 500	**PLAN:** 2B

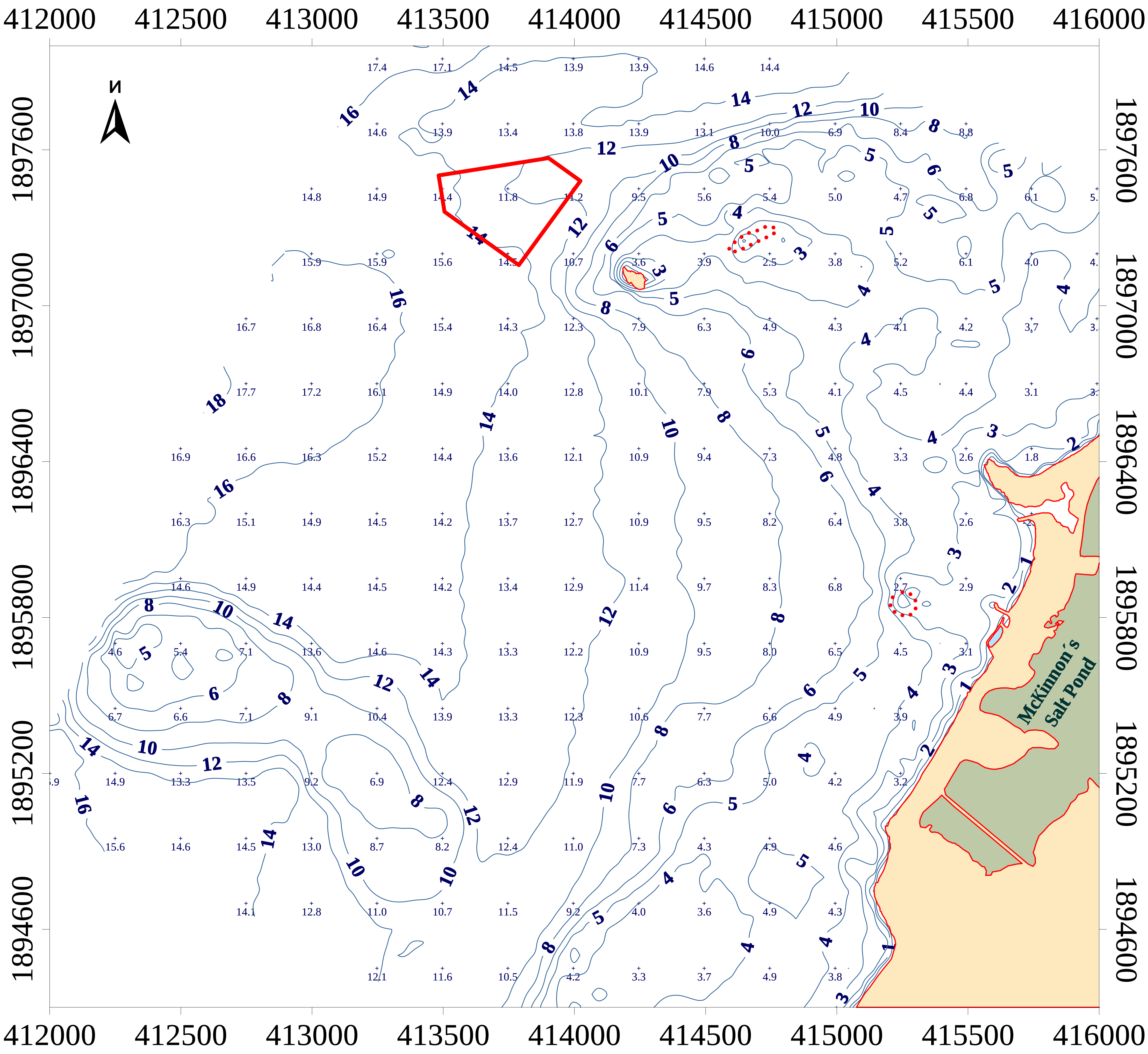




LEGEND

- Technical filling and paving areas
- Rock Coastal Defense Structure
- First Line Structures
- Second Line Structures
- Third Line Structures
- Wall
- Equilibrium Profile

GAMMA TECNOLOGIA Y MEDIO AMBIENTE	**MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA**
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.
MADE BY: BSc. Pavel Morales Díaz	
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Type Profile Sectors 3 and 4
DATE: June 2022	**SCALE:** X 1: 200 Y 1: 2 500 — **PLAN:** 2C



LEGEND

- Geographic North
- Coastal Line
- Rock heads
- Isobaths
- Proposed Borrow Area

Transverse Mercator Projection

Antigua 1943 Datum

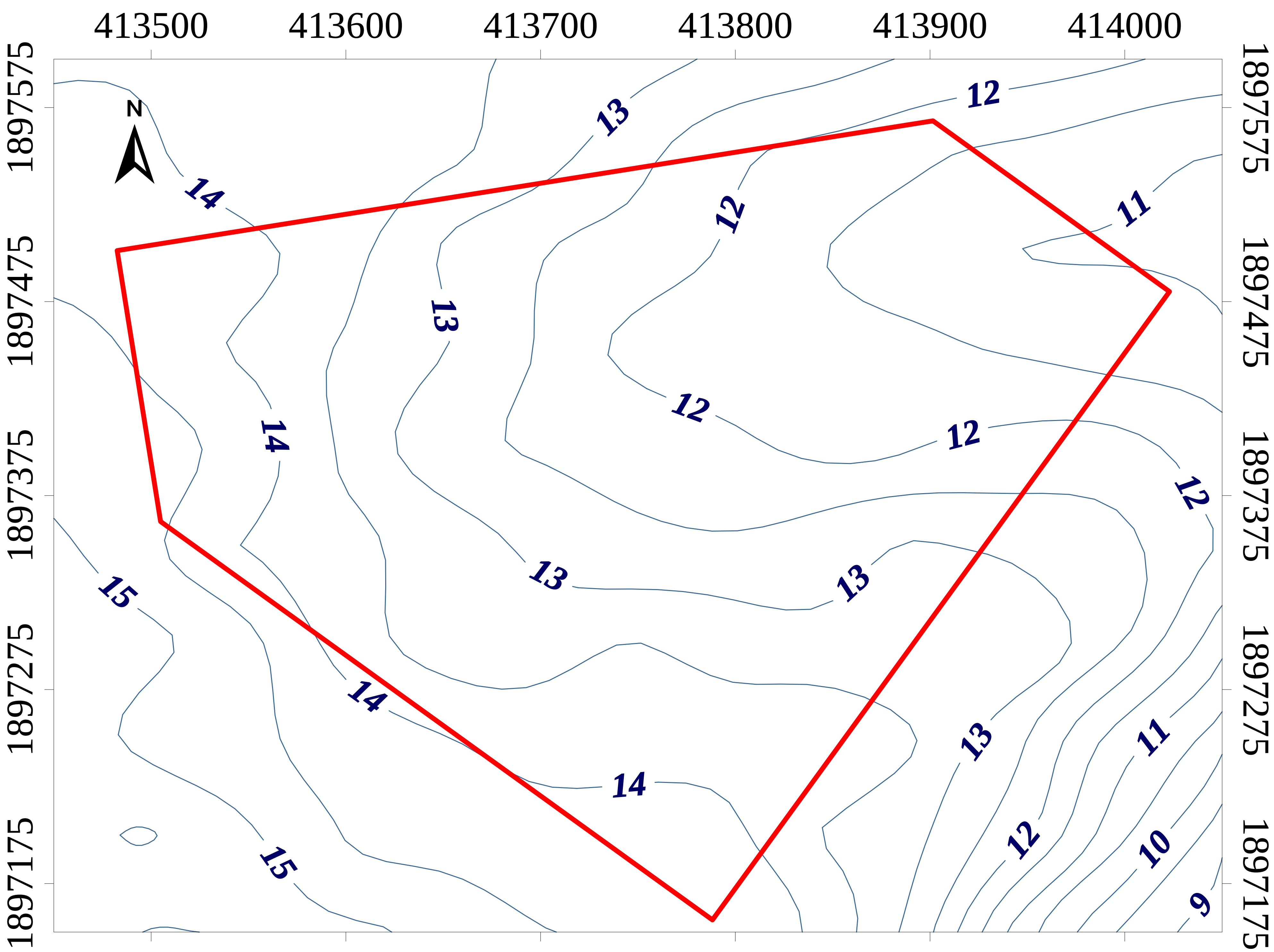
British West Indies Grid Coordinates System

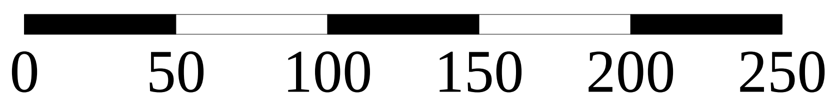
Depht in meters referred to mean sea level

Isobaths every 1.0 m

0 250 500 750 1000 1250

GAMMA	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT LEADER: BSc. Pavel Morales Díaz	EXECUTIVE PROJECT: Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	TITLE: Runaway Bay Beach Bathymetric Plan	
DATE: June 2022	SCALE: 1:15 000	PLAN: 3





LEGEND

Geographic North

Isobaths

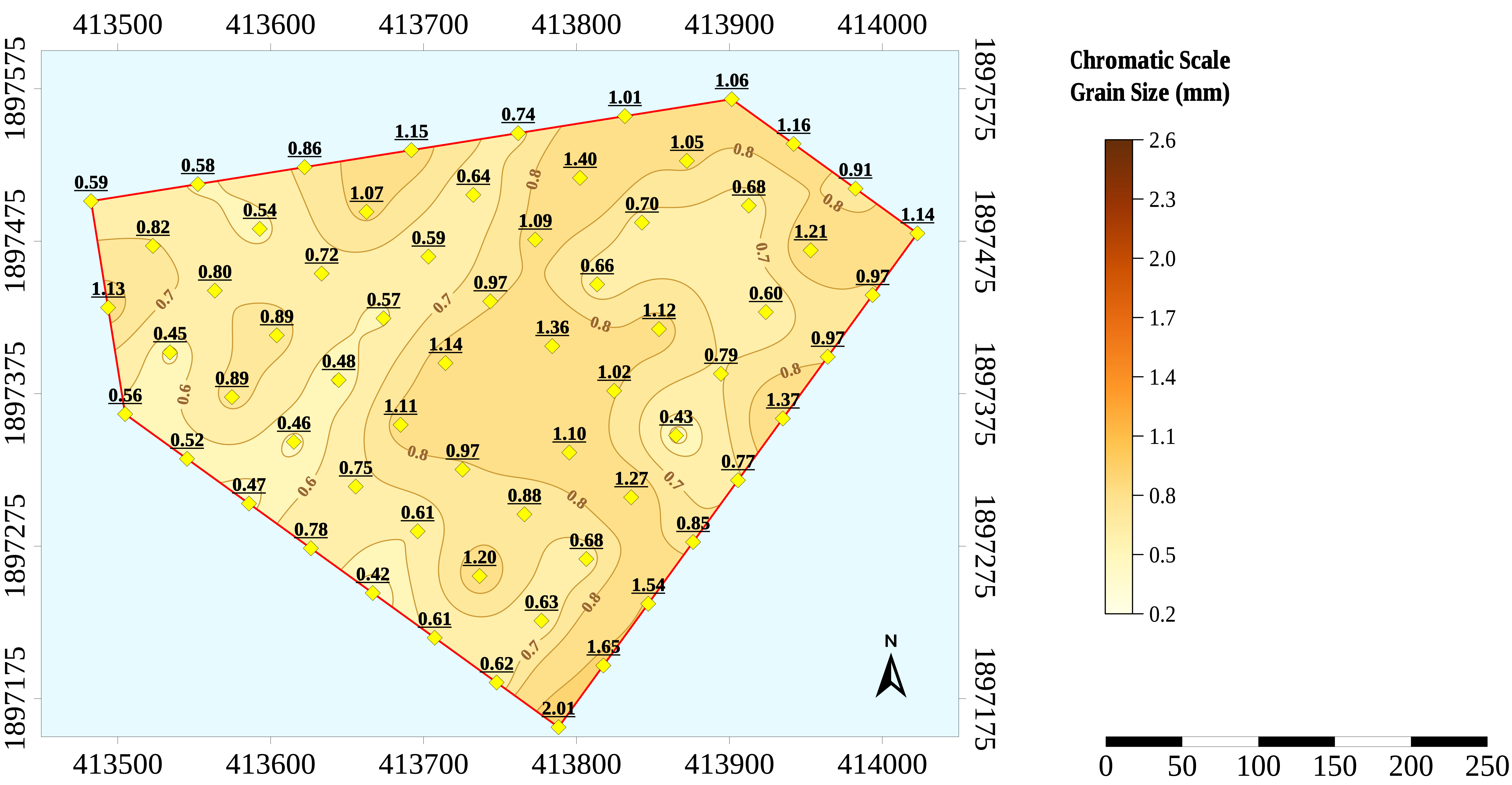
Delimitation

Transverse Mercator Projection
Antigua 1943 Datum
British West Indies Grid Coordinates System

Depht in meters referred to mean sea level

Isobaths every 0.5 m

GAMMA TECNOLOGÍA Y MEDIO AMBIENTE	**MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA**	
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Great Sister Basin Bathymetric Survey	
DATE: June 2022	**SCALE:** 1:2 500	**PLAN:** 4



LEGEND

Geographic North

Isolines of equal grain size

Sampling Stations

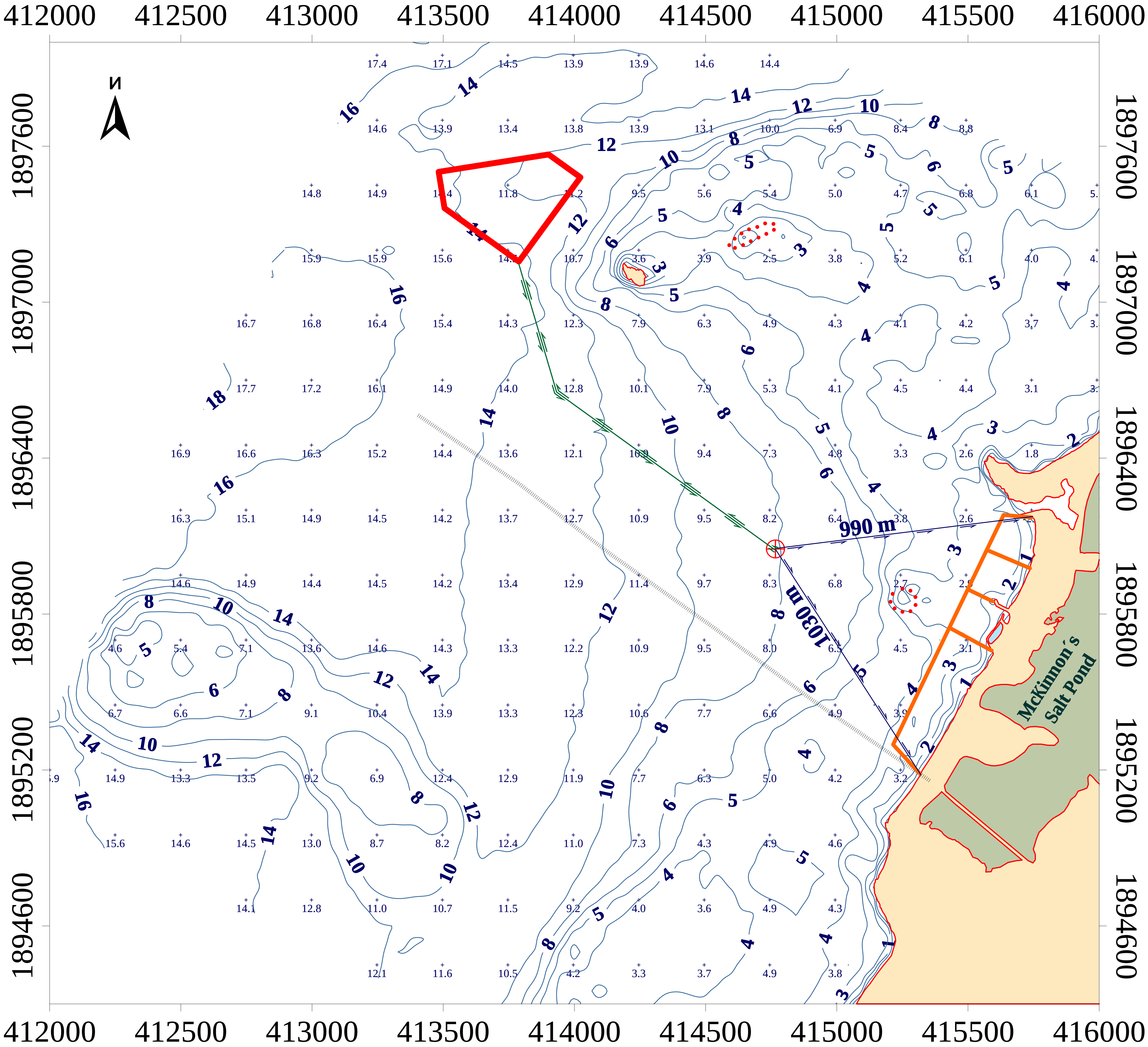
Delimitation

Transverse Mercator Projection
Antigua 1943 Datum
British West Indies Grid Coordinates System

Grain Size in millimeters

Isolines of equal grain size every 0.2 mm

GAMMA TECNOLOGIA Y MEDIO AMBIENTE	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Great Sister Basin Grain Size Analysis Results	
DATE: June 2022	**SCALE:** 1:2 500	**PLAN:** 5



LEGEND

- Geographic North
- Coastal Line
- Rock heads
- Isobaths
- Proposed Borrow Area
- Approach Points
- Recomended Approach Path
- Sectors Limits
- Distance between Approach Points and Discharge Sectors
- Submarine Oil Pipeline

Transverse Mercator Projection

Antigua 1943 Datum

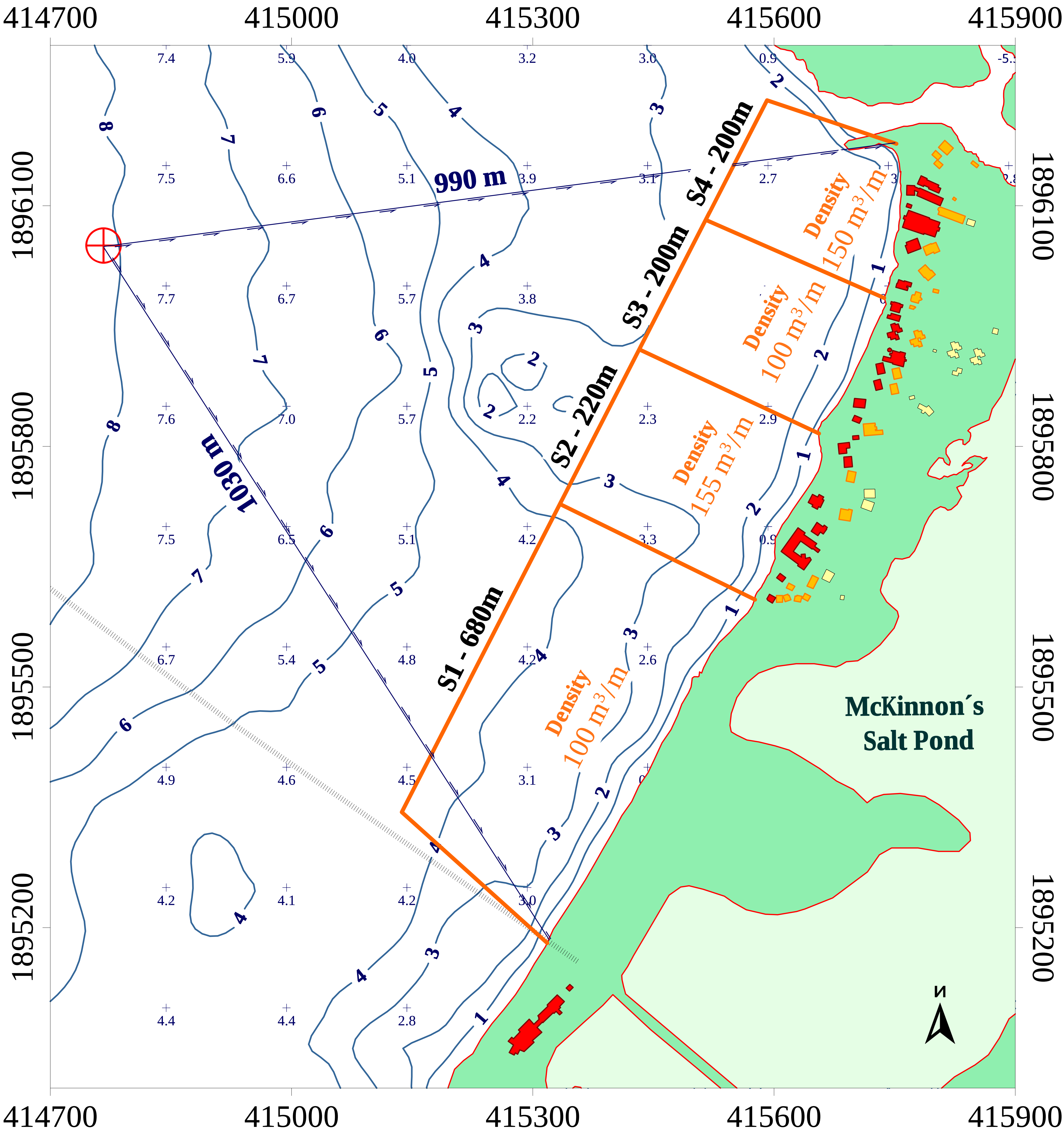
British West Indies Grid Coordinates System

Depht in meters referred to mean sea level

Isobaths every 1.0 m

0 250 500 750 1000 1250

GAMMA	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Approach Points and Discharge Sectors	
DATE: June 2022	**SCALE:** 1:15 000	**PLAN:** 6



LEGEND

- Geographic North
- Coastal Line
- -2 Isobaths
- First Line Structures
- Second Line Structures
- Third Line Structures
- Proposed Borrow Area
- Approach Points
- Sectors Limits
- Distance between Approach Points and Discharge Sectors
- Submarine Oil Pipeline

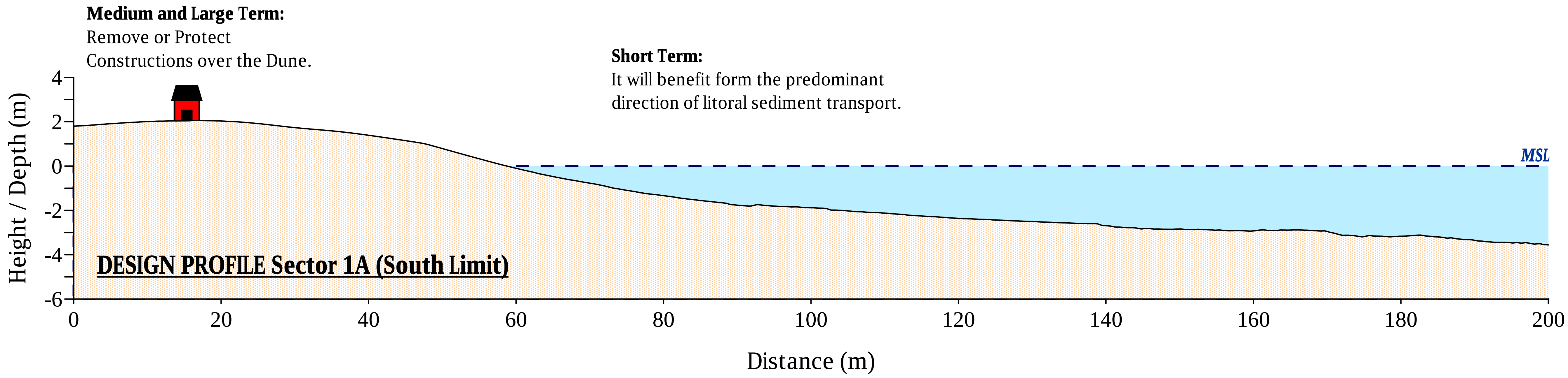
0 100 200 300 400 500

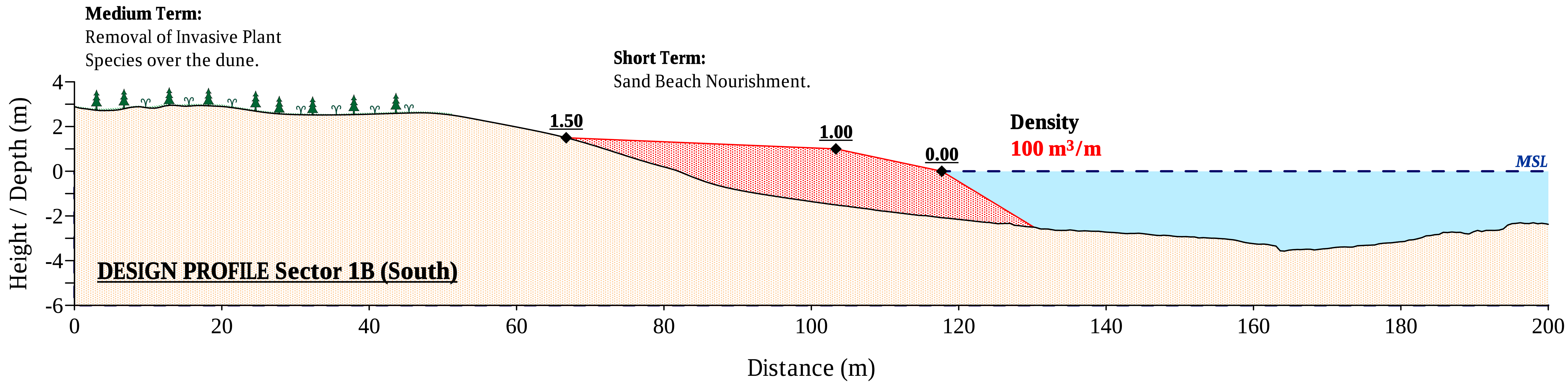
Transverse Mercator Projection
Antigua 1943 Datum
British West Indies Grid Coordinates System

Height in meters referred to mean sea level

Isobaths every 1.0 m

GAMMA TECNOLOGÍA Y MEDIO AMBIENTE	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.
MADE BY: BSc. Pavel Morales Díaz	
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Nourishment Density by Sector
DATE: June 2022	**SCALE:** 1:5 000 — **PLAN:** 6A





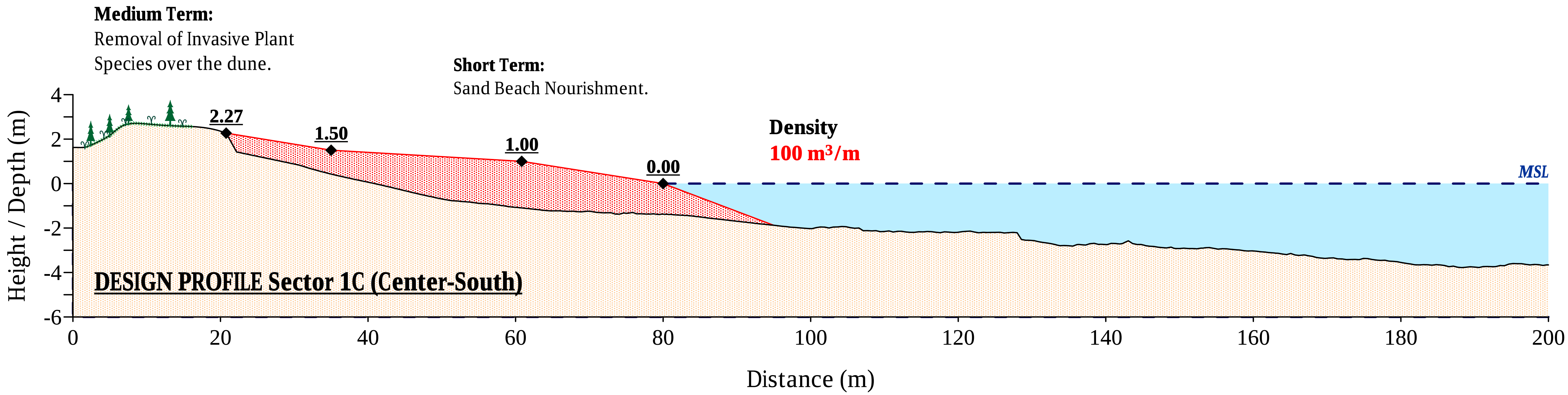
LEGEND

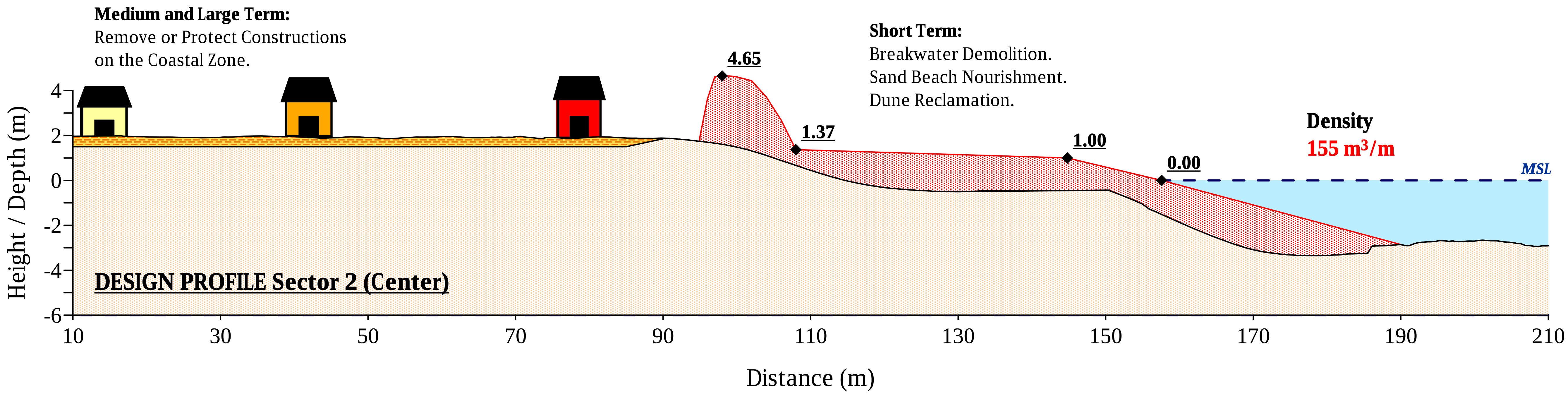
Predominance of Invasive Plant Species

First Line Structures

Design Profile

GAMMA TECNOLOGÍA Y MEDIO AMBIENTE	**MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA**	
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Design Profiles Sectors 1(A) and 1(B)	
DATE: June 2022	**SCALE:** X 1: 600 Y 1: 200	**PLAN:** 7A

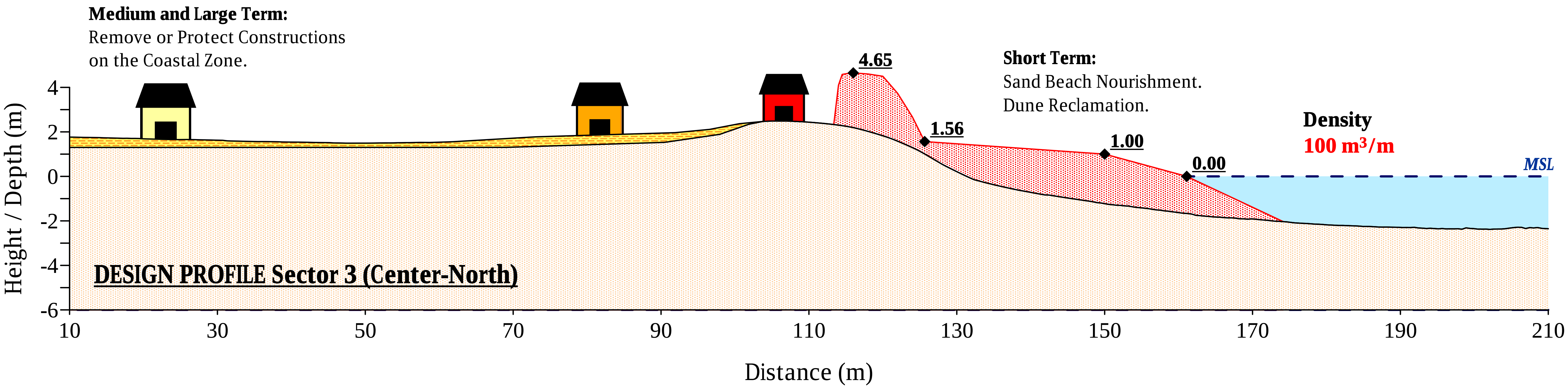


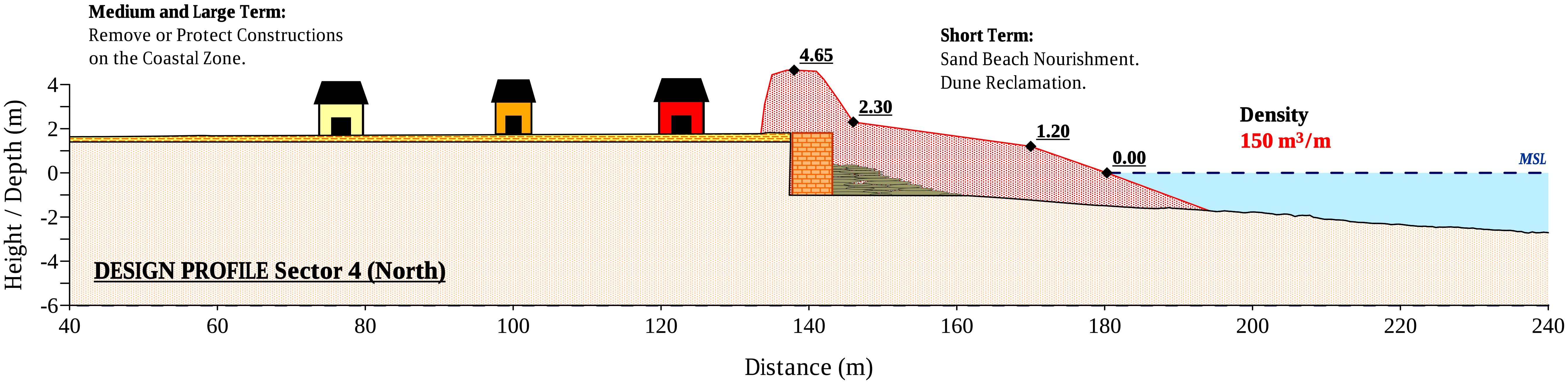


LEGEND

- Technical filling and paving areas
- Design Profile
- First Line Structures
- Second Line Structures
- Third Line Structures
- Predominance of Invasive Plant Species

GAMMA Tecnología y Medio Ambiente	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.
MADE BY: BSc. Pavel Morales Díaz	
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Design Profiles Sectors 1(C) and 2
DATE: June 2022	**SCALE:** X 1: 600 Y 1: 200 **PLAN:** 7B



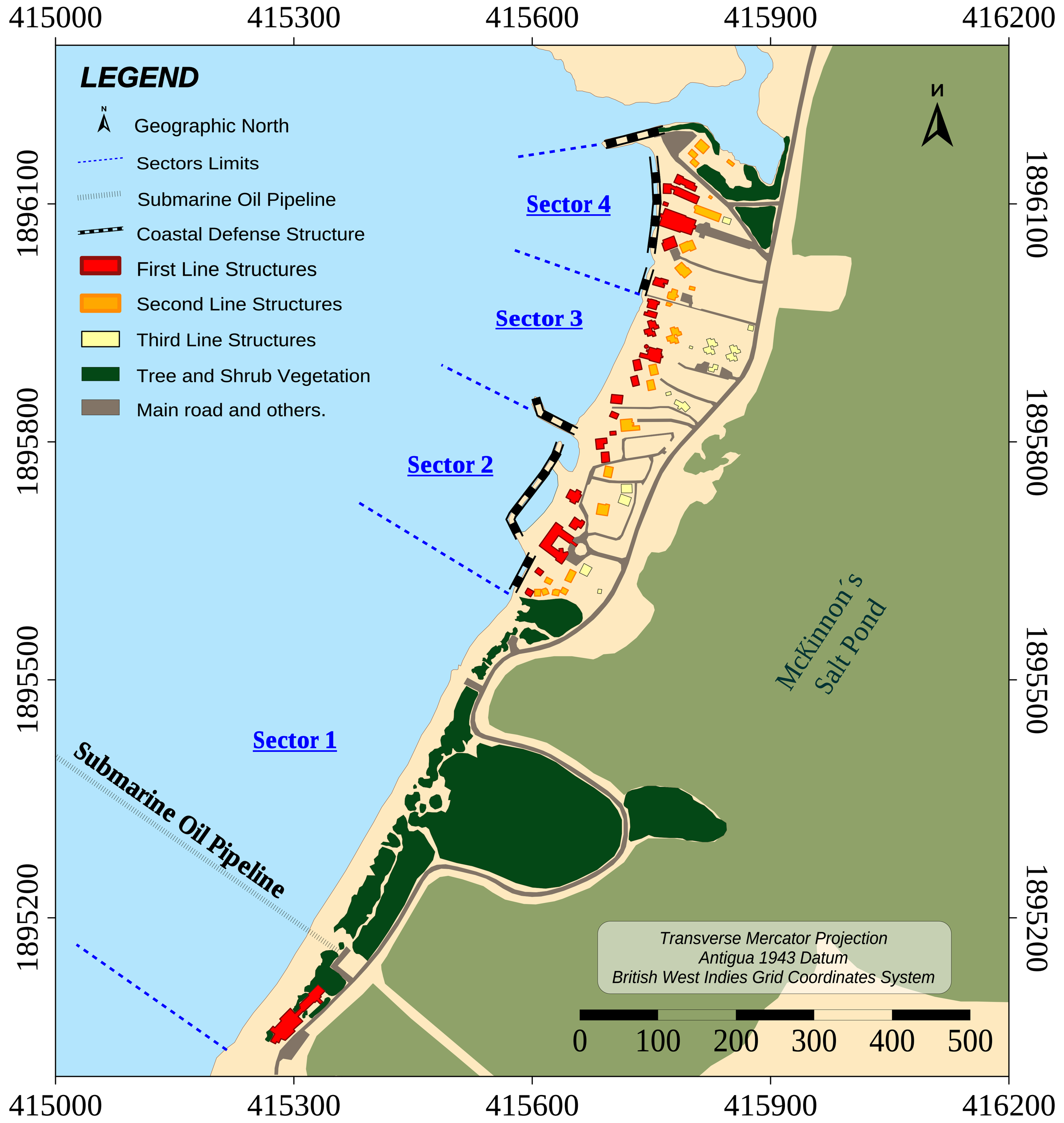


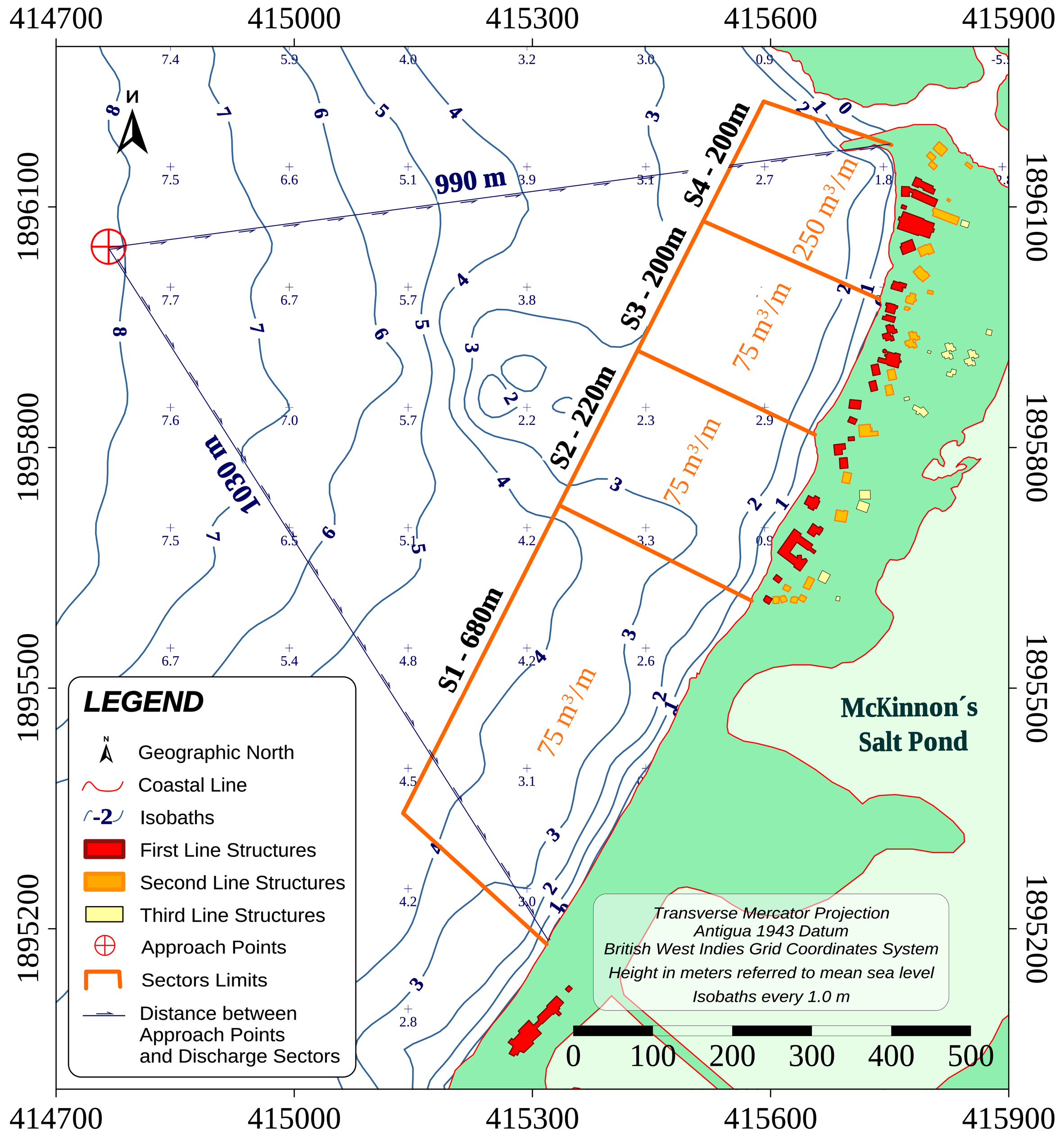
LEGEND

- Design Profile
- Technical filling and paving areas
- Rock Coastal Defense Structure
- First Line Structures
- Second Line Structures
- Third Line Structures
- Wall

GAMMA Tecnología y Medio Ambiente	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA		
PROJECT LEADER: BSc. Pavel Morales Díaz	**EXECUTIVE PROJECT:** Runaway Bay Beach, Antigua and Barbuda. Manage and Recovery.		
MADE BY: BSc. Pavel Morales Díaz			
REVIEWED BY: MSc. Leonel I. Peña Fuentes	**TITLE:** Runaway Bay Beach Design Profile Sectors 3 and 4		
DATE: June 2022	**SCALE:** X 1: 600 Y 1: 200	**PLAN:**	7C

REHABILITATION PROJECT FOR RUNAWAY BAY BEACH





EROSION EVIDENCE

- Monitoring Results (Period 1995-2015).
- Photografic Evidence (Hurricane Luis, 1995 effects).
- Scarped Dune (Sector 1).
- Beach Rocks (Sectors 1 and 3).
- Damage to Vegetation (Sector 1).
- Damage to Structures on the Dune (Sectors 3 y 4).


S4 (1994) Before Hurricane Luis


S4 (1996) After Hurricane Luis


Sector 4 at Present (2022)

EROSION CAUSES

Of ANTHROPOGENIC origin:

- Occupation of the dune by hard structures that intensify the storm waves reflection, favoring the transport of sediments offshore.
- Occupation of the coastal zone by breakwaters and groynes that interrupt the coastal sediments transport and favor rip currents.
- Layers of filling on the dune, favoring the stiffening of the ground and partly contributing to the reflection of storm waves.
- Dredging of the access channel to Marina Bay, which contributes to interrupting the transport of sand from Dickenson Bay.

Of NATURAL origin:

- Tidal waves generated by tropical cyclones in a new active period started in 1994, in the North Atlantic basin.
- Wave difraction process are generated by shallows and headlands that favor rip currents appearance in certain areas of the beach.
- Climate Change-induced rise in mean sea level.

SHORT TERM MEASURES

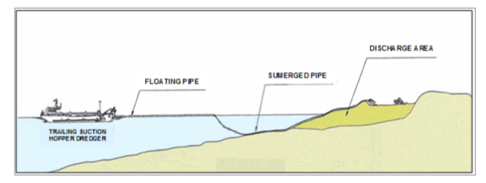
Runaway Bay Beach	Proposed measures	Comments
Sector 1	Beach nourishment. Dune recovery. Dune reforestation. Removal of invasive plants species.	Analyze possibility of removing or protecting the foundations of structures on the dune.
Sector 2	Removal coastal defenses structures. Beach nourishment. Dune recovery. Dune reforestation. Protection of buidings foundations.	If not possible to remove the hard structures, it is recommended to assess the condition of their foundations.
Sector 3	Beach nourishment. Dune recovery. Dune reforestation. Removal of invasive plants species.	Analyze possibility of removing or protecting the foundations of structures on the dune.
Sector 4	Removal coastal defenses structures. Beach nourishment. Dune recovery. Dune reforestation. Protection of buidings fundations.	If the wall is removed, analyze to reconfigure, displace the dune landwards, or protect foundations of vulnerable structures.

BEACH NOURISHMENT VOLUMES

SECTOR 1	500 m	100 m^3/m	50 000 m^3
SECTOR 2	220 m	155 m^3/m	34 100 m^3
SECTOR 3	200 m	100 m^3/m	20 000 m^3
SECTOR 4	200 m	150 m^3/m	30 000 m^3

DREDGING CYCLES

Sailing to the Dredging Area → Dredging → Sailing to the Discharge Area → Connecting to Floating Pipe → Discharge in Filling Area → Disconnecting to Floating Pipe



LONG TERM MEASURES

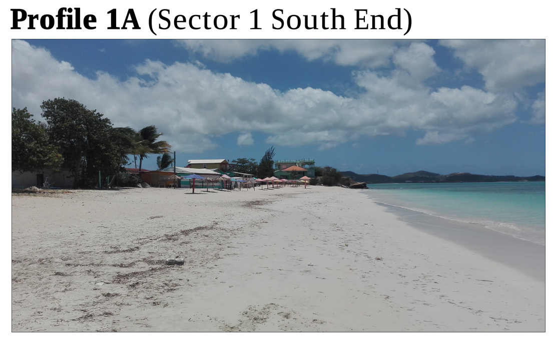
- Creation of a legal framework that promotes and guarantee the preservation of the beach.
- Monitoring the effectiveness of the actions to be carried out in the short and medium term, and the evolution of the beach, in order to define when new actions are required.
- Periodic application of Artificial Sand Nourishment.
- Maintenance of the dune, its vegetation cover, and protection works for the foundations of the buildings that remain in the area.

SECTOR 1

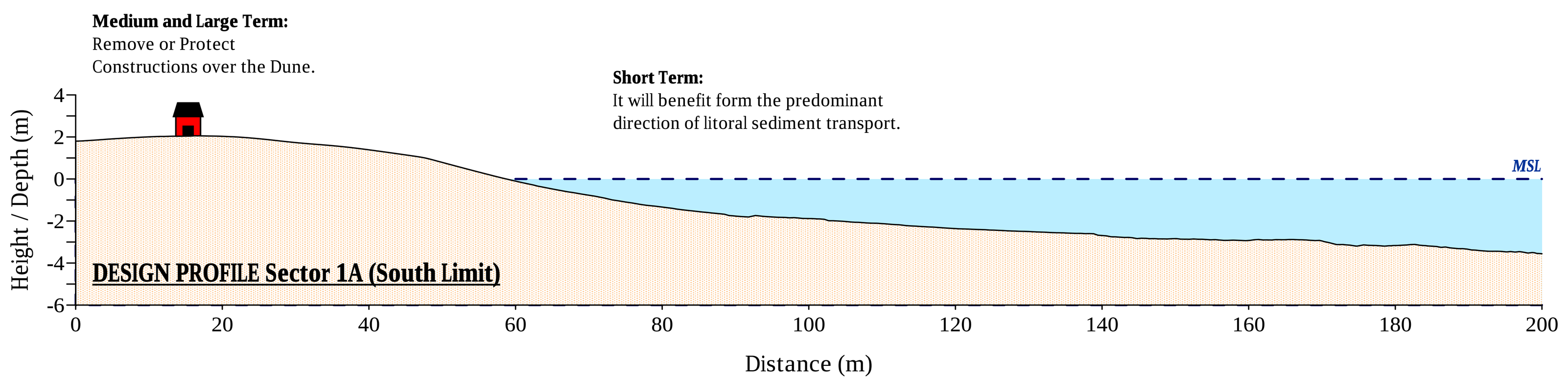
Lenght: 680 m.
Actual Condition:

Profiles: 3.
Short, Medium and Long Term Measures:

Profile 1A (Sector 1 South End)

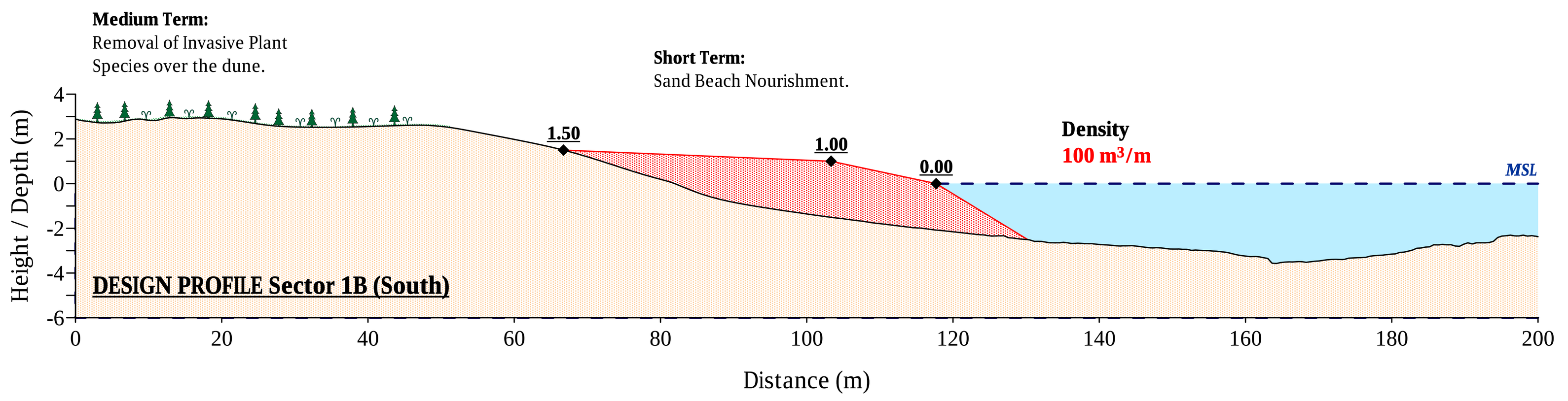


Morphology	Small Bar. Low Berm Crest. Occupied Dune. Beach Width: around 30m.
Aesthetic	Typical Vegetation Replaced by Buildings. Anthropized Coastal Zone.
Funcionality	Beach profile decreased dissipative capacity due to an occupied and unforest Dune, and a low volume sand Bars.



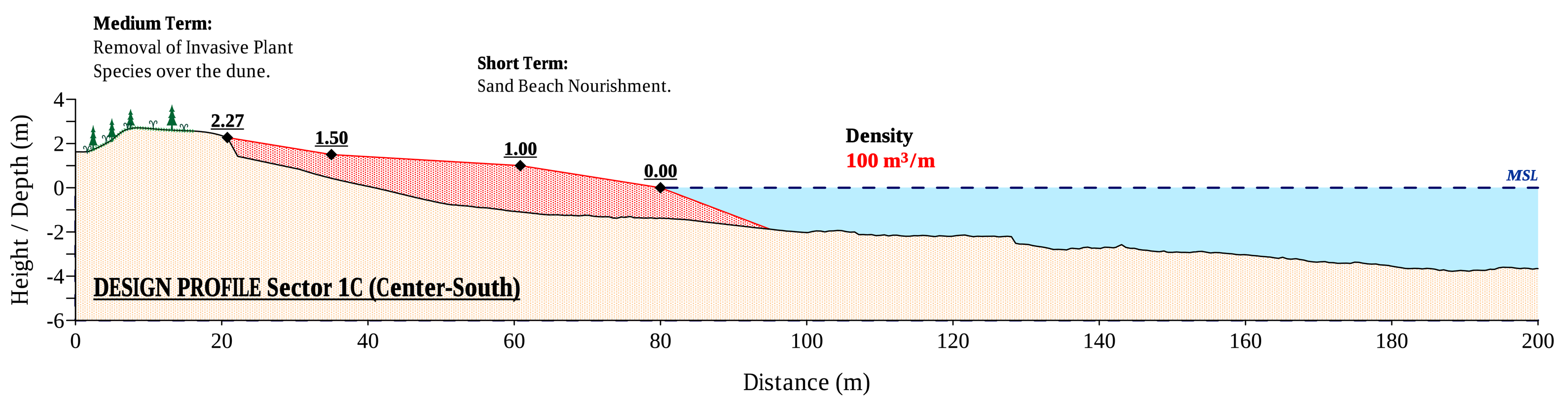
Profile 1B (Sector 1 Centre)

Morphology	Small Bar. Low Berm Crest. Scarped Dune. Beach Width: around 25m.
Aesthetic	Invasive Plants replaced Typical Vegetation. Modified Natural Landscape.
Funcionality	Slight decreased beach profile dissipative capacity due to a low volume sand Bars. Non-ideal vegetation for sand retention.



Profile 1C (Sector 1 North End)

Morphology	Too small Bar and Berm Crest. Technical filling on Scarped Dune. Beach Width: less than 20m.
Aesthetic	Invasive Plants repleaced Typical Vegetation. Beach rocks. Modified Natural Landscape.
Funcionality	Decreased beach profile dissipative capacity due to a low volume sand Bar and Berm. Filling on the Dune. Non-ideal vegetation for sand retention.

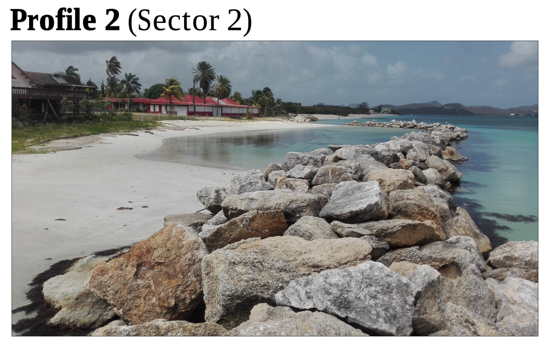


SECTOR 2 - 4

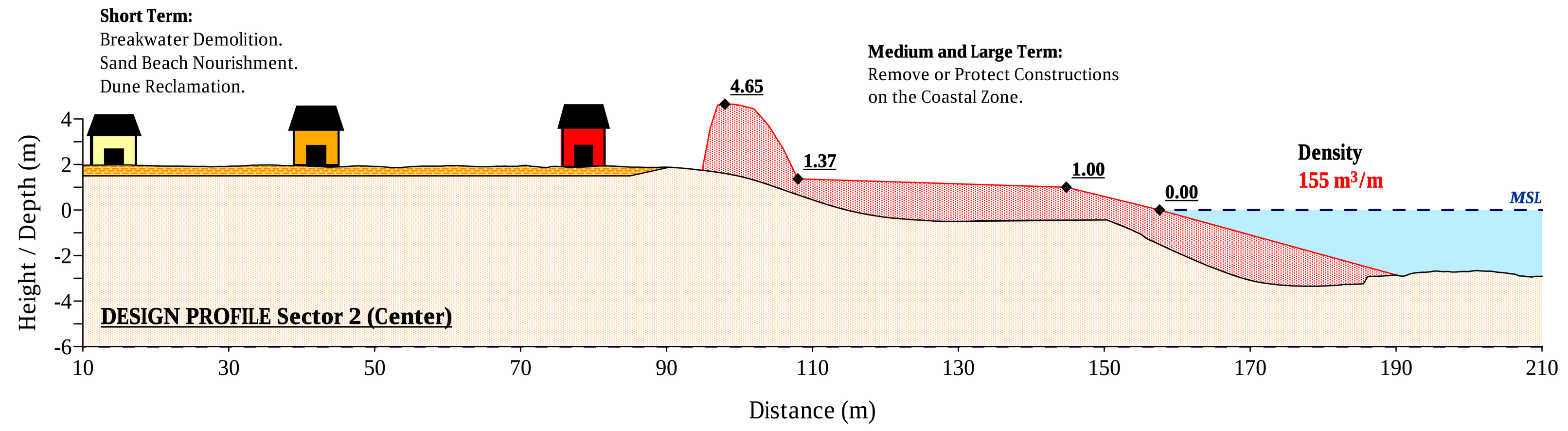
Lenght: 220 m - 200 m - 200 m
Actual Condition:

Profiles: 3 (1 by Sector)
Short, Medium and Long Term Measures:

Profile 2 (Sector 2)

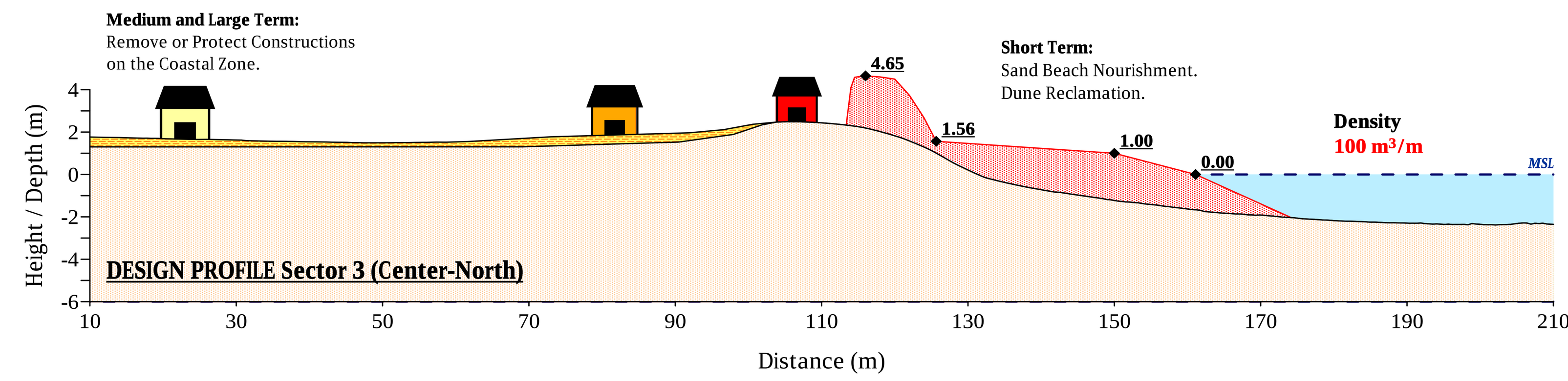


Morphology	Enclosed Beach. Stiffening of Seabed behind, and steep slope at the foot, of the Breakwater.
Aesthetic	Anthropized Beach. Occupied Dune. Narrow Sun Strip. Enclosed water eutrophication.
Funcionality	Minimal water circulation favors eutrophication. Breakwater interrupt income of sand so, protect properties but not allow for beach development.



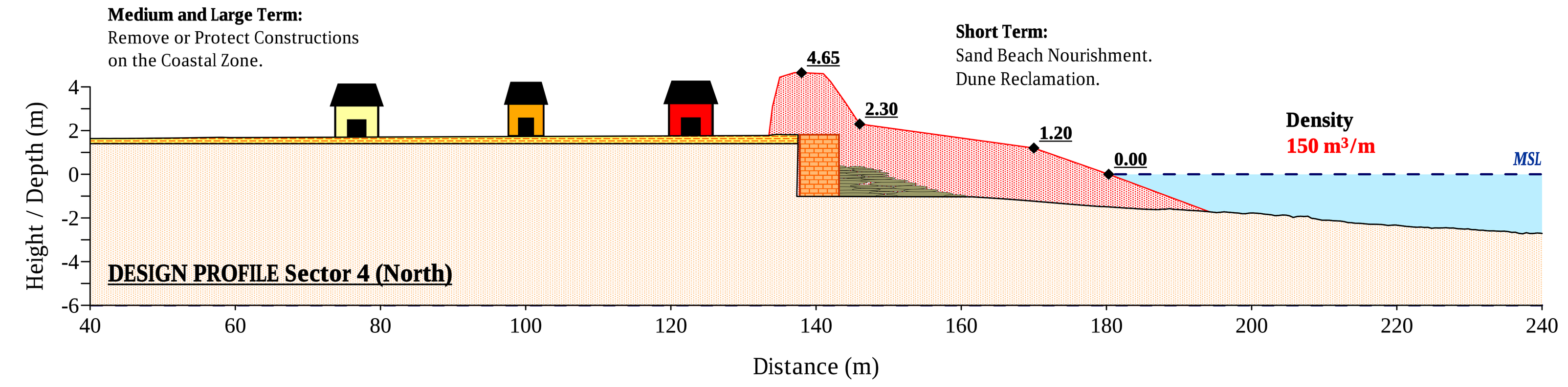
Profile 3 (Sector 3)

Morphology	Supported on Groyne. Occupied Dune. Small Bar and Berm Crest. Rocks (N). Little Sun Area.
Aesthetic	Invasive Plants repleaced Typical Vegetation. Beach rocks (N). Modified Natural Landscape.
Funcionality	Decreased beach profile dissipative capacity due to an occupied Dune and low volume sand Bars. Non-ideal vegetation for sand retention.



Profile 4 (Sector 4)

Morphology	Buildings, Walls and a Rock Revetment. Some sand in the submerged profile.
Aesthetic	Very Anthropized Coastal Zone. Beach was lost more than 20 years ago due to erosion.
Funcionality	Beach profile has almost totally lost its dissipative capacity due to an intensive erosion process. Reflective structures within reach of the waves.



SOLUTION COMPONENTS

MORPHOLOGICAL: Conforming a beach profile, with the presence of the different morphological elements that make it up, and a notable increase in the Sun Strip width.

AESTHETIC: Advancing in the gradual restoration of the natural aesthetic and landscape values of the original ecosystem.

FUNCTIONAL (Recreational and Tourist): From the achievement of the precepts relative to the conformation of a profile with adequate Sun Strip and Carrying Capacity, and an attractive natural image.

FUNCTIONAL (Coastal Defense Works Based on Ecosystem Adaptation): Beaches with sufficient volumes of sand, gently sloping profiles, powerful bars, berms and dunes, and an adequate design, ensure: effective dissipation of wave energy typical of strong storm waves generated by extreme weather events; and the protection of the constructions in their shelter.

GAMMA TECNOLOGIA Y MEDIO AMBIENTE	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT LEADER: BSc. Pavel Morales Díaz	EXECUTIVE PROJECT: Rehabilitation Project for Runaway Bay Beach, Antigua and Barbuda.	
MADE BY: BSc. Pavel Morales Díaz		
REVIEWED BY: MSc. Leonel I. Peña Fuentes	TITLE: Runaway Bay Beach PROJECT RESUME	
DATE: March 2023	SCALE: a)1:5 000 b-c) X 1: 600 Y 1: 200	PLAN: 8

ANEXO I

Runaway Bay Beach

Results of Grain Size Analysis

SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **MS RB CENTER**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

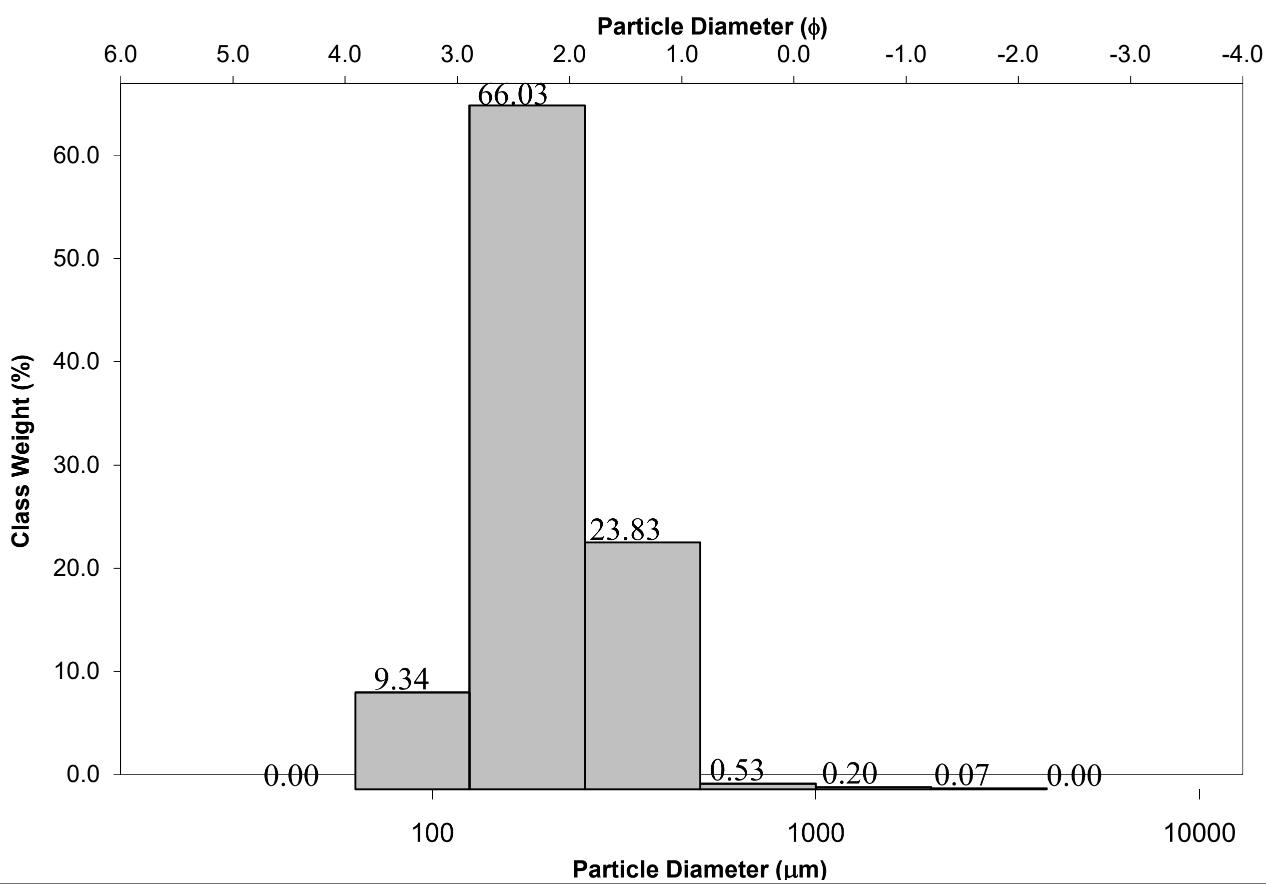
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	126.0	1.386
MEDIAN or D_{50}:	191.7	2.383
D_{90}:	382.7	2.989
(D_{90} / D_{10}):	3.038	2.157
$(D_{90} - D_{10})$:	256.7	1.603
(D_{75} / D_{25}):	1.689	1.377
$(D_{75} - D_{25})$:	101.6	0.756

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.1%	COARSE SAND:	0.5%
SAND:	99.9%	MEDIUM SAND:	23.9%
MUD:	0.0%	FINE SAND:	66.1%
		V FINE SAND:	9.2%
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:	0.1%	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 ($\bar{x}$):	231.1	198.3	2.334	202.2	2.306	Fine Sand
SORTING (σ):	133.1	1.509	0.594	1.580	0.660	Moderately Well Sorted
SKEWNESS (Sk):	8.239	0.512	-0.512	0.122	-0.122	Coarse Skewed
KURTOSIS (K):	143.3	4.969	4.969	1.234	1.234	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **MS RB NORTH**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

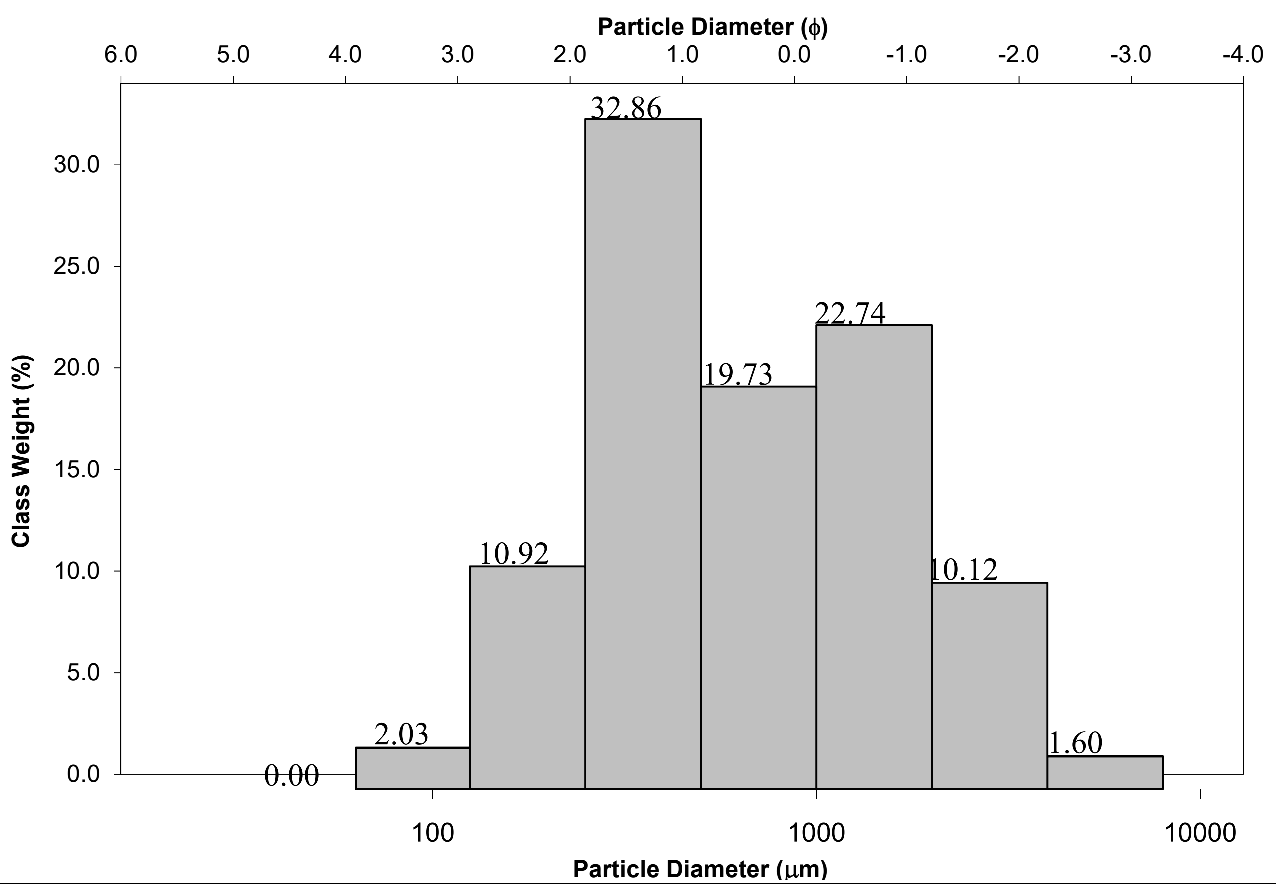
	μm	φ
MODE 1:	375.0	1.500
MODE 2:	1500.0	-0.500
MODE 3:		
D_{10}:	207.6	-1.170
MEDIAN or D_{50}:	579.6	0.787
D_{90}:	2250.6	2.268
(D_{90} / D_{10}):	10.84	-1.938
$(D_{90} - D_{10})$:	2042.9	3.438
(D_{75} / D_{25}):	4.138	-3.922
$(D_{75} - D_{25})$:	1012.0	2.049

GRAIN SIZE DISTRIBUTION

GRAVEL:	11.7%	COARSE SAND:	19.7%
SAND:	88.3%	MEDIUM SAND:	32.9%
MUD:	0.0%	FINE SAND:	10.9%
		V FINE SAND:	2.0%
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:	1.6%	FINE SILT:	0.0%
V FINE GRAVEL:	10.1%	V FINE SILT:	0.0%
V COARSE SAND:	22.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1034.6	646.6	0.629	647.5	0.627	Coarse Sand
SORTING (σ):	1044.3	2.472	1.306	2.540	1.345	Poorly Sorted
SKEWNESS (Sk):	2.258	0.176	-0.176	0.146	-0.146	Coarse Skewed
KURTOSIS (K):	9.587	2.361	2.361	0.878	0.878	Platykurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **MS RB SOUTH**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

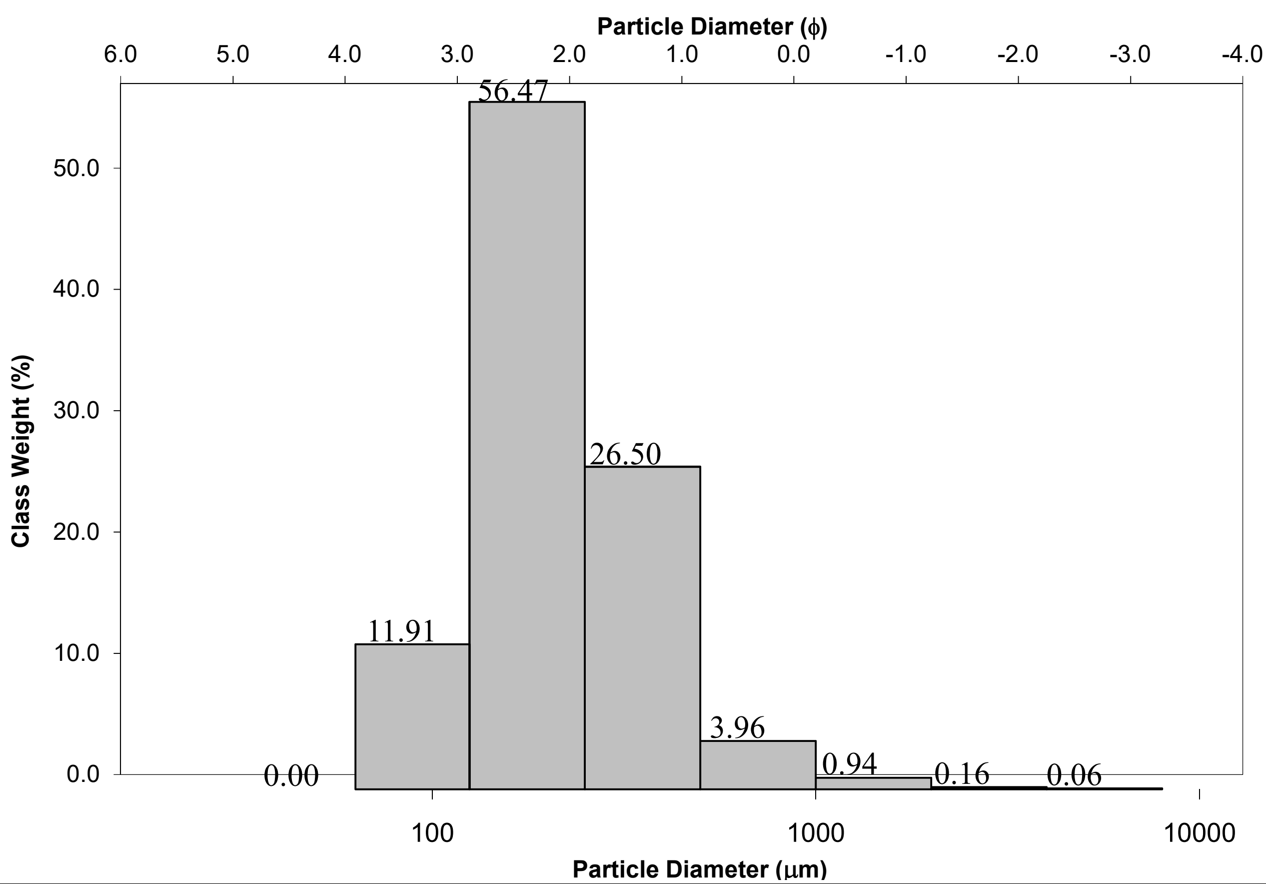
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	112.6	1.184
MEDIAN or D_{50}:	199.7	2.324
D_{90}:	440.2	3.150
(D_{90} / D_{10}):	3.909	2.661
$(D_{90} - D_{10})$:	327.6	1.967
(D_{75} / D_{25}):	2.024	1.582
$(D_{75} - D_{25})$:	150.5	1.017

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.2%	COARSE SAND:	4.0%
SAND:	99.8%	MEDIUM SAND:	26.5%
MUD:	0.0%	FINE SAND:	56.5%
		V FINE SAND:	11.8%
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:	0.1%	FINE SILT:	0.0%
V FINE GRAVEL:	0.2%	V FINE SILT:	0.0%
V COARSE SAND:	0.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	268.9	212.4	2.235	214.6	2.220	Fine Sand
SORTING (σ):	255.9	1.707	0.772	1.709	0.773	Moderately Sorted
SKEWNESS (Sk):	9.975	0.884	-0.884	0.125	-0.125	Coarse Skewed
KURTOSIS (K):	177.6	5.289	5.289	1.048	1.048	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **RB 1**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

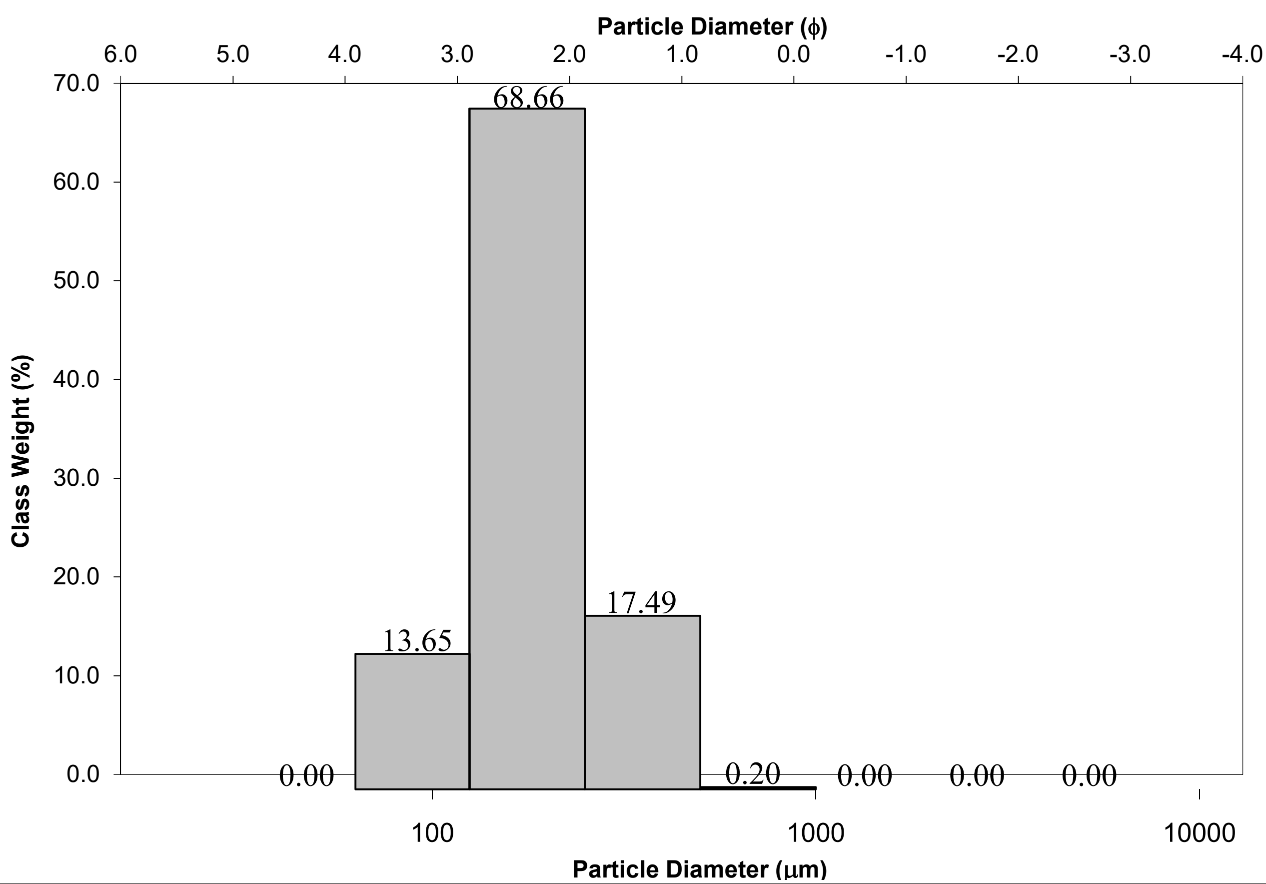
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	104.6	1.559
MEDIAN or D_{50}:	180.6	2.469
D_{90}:	339.3	3.257
(D_{90} / D_{10}):	3.244	2.089
$(D_{90} - D_{10})$:	234.7	1.698
(D_{75} / D_{25}):	1.655	1.345
$(D_{75} - D_{25})$:	91.96	0.727

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.2%
SAND:	100.0%	MEDIUM SAND:	17.5%
MUD:	0.0%	FINE SAND:	68.8%
		V FINE SAND:	13.5%
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 ($\bar{x}$):	208.8	182.4	2.455	183.6	2.445	Fine Sand
SORTING (σ):	86.71	1.475	0.561	1.538	0.621	Moderately Well Sorted
SKEWNESS (Sk):	1.395	0.090	-0.090	0.043	-0.043	Symmetrical
KURTOSIS (K):	5.819	3.357	3.357	1.324	1.324	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **RB 2**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

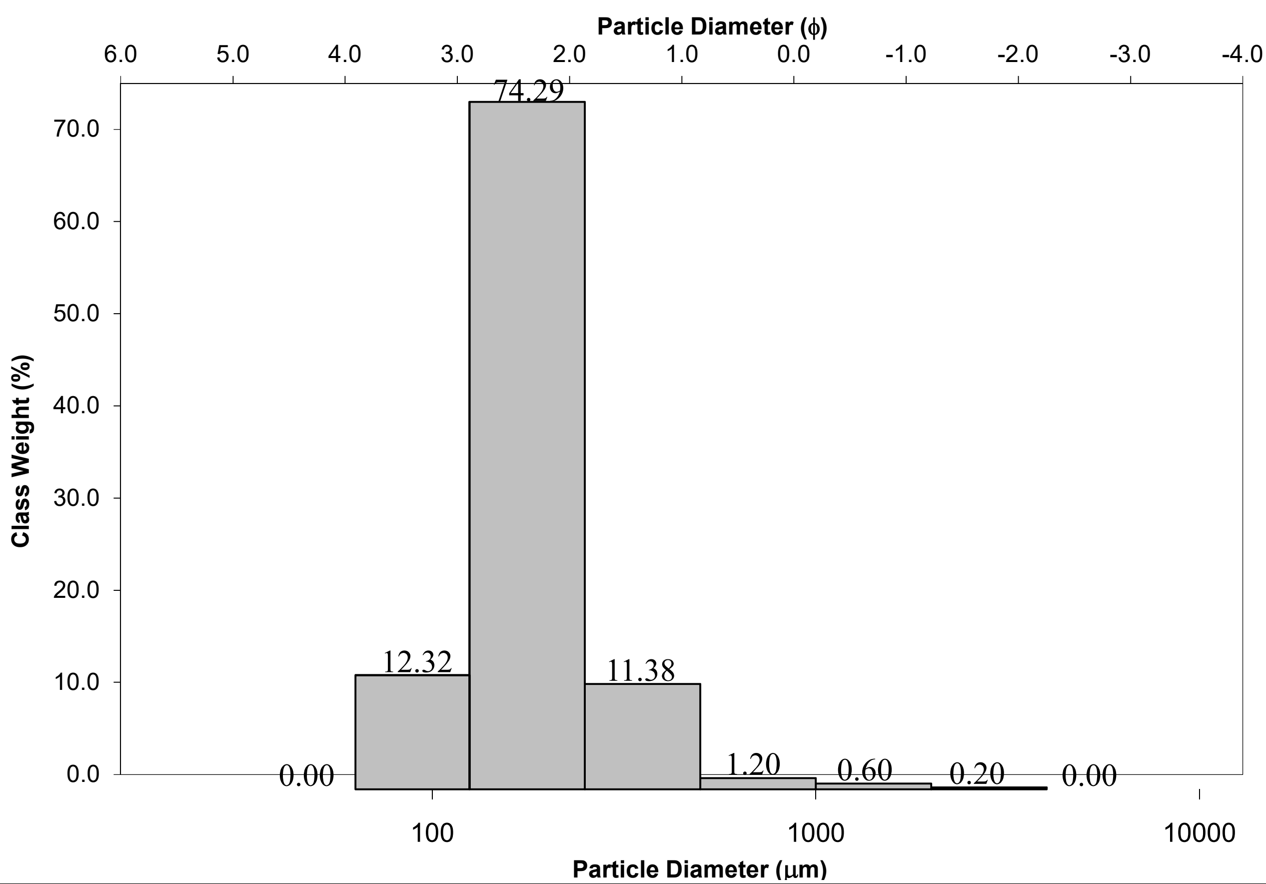
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	110.5	1.702
MEDIAN or D_{50}:	177.8	2.492
D_{90}:	307.4	3.178
(D_{90} / D_{10}):	2.783	1.868
(D_{90} - D_{10}):	196.9	1.477
(D_{75} / D_{25}):	1.593	1.312
(D_{75} - D_{25}):	83.56	0.672

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.2%	COARSE SAND:	1.2%
SAND:	99.8%	MEDIUM SAND:	11.4%
MUD:	0.0%	FINE SAND:	74.4%
		V FINE SAND:	12.2%
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:	0.2%	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 ($\bar{x}$):	217.7	182.1	2.457	177.8	2.492	Fine Sand
SORTING (σ):	184.7	1.522	0.606	1.495	0.580	Moderately Well Sorted
SKEWNESS (Sk):	9.162	1.499	-1.499	0.030	-0.030	Symmetrical
KURTOSIS (K):	117.8	10.13	10.13	1.415	1.415	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **RB 3**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

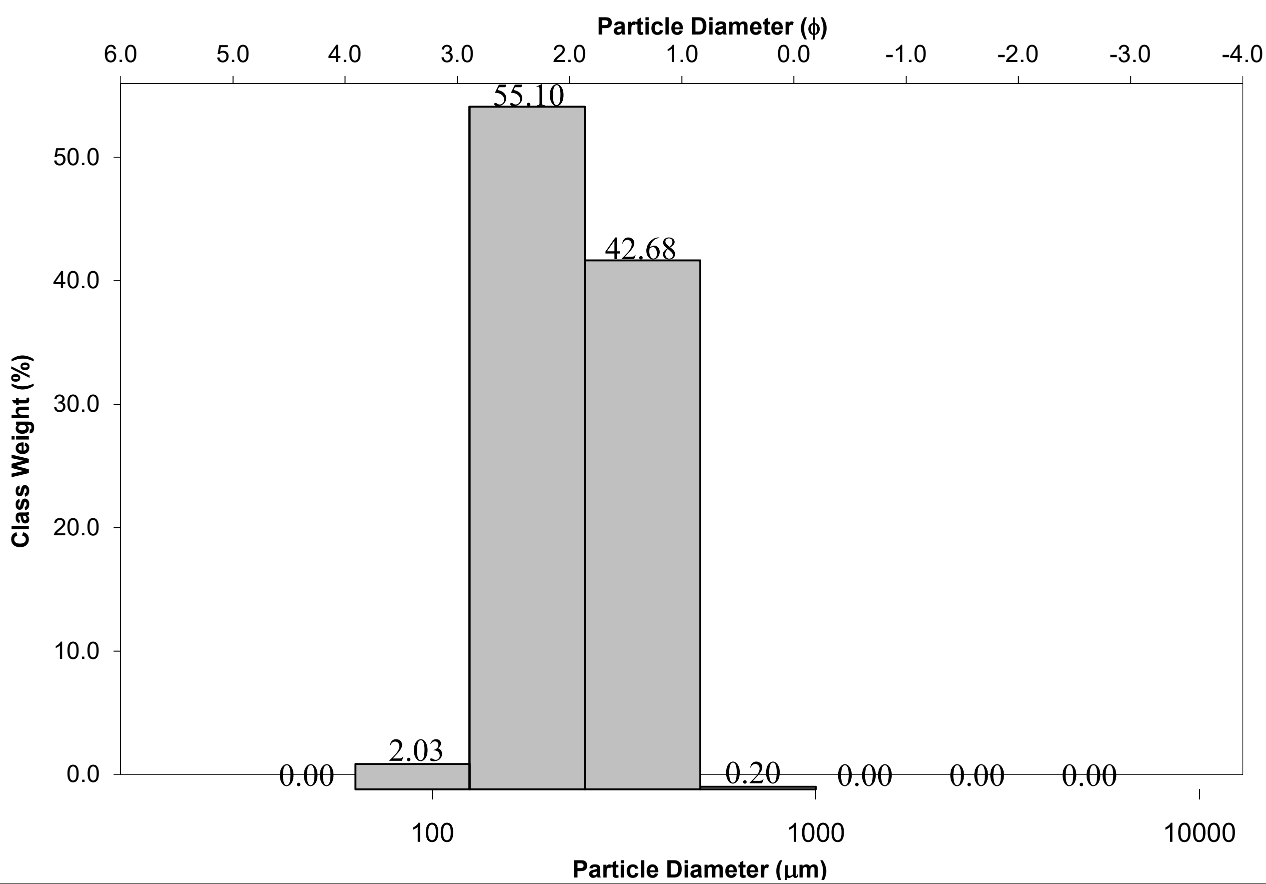
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	138.2	1.230
MEDIAN or D_{50}:	228.6	2.129
D_{90}:	426.4	2.855
(D_{90} / D_{10}):	3.085	2.322
(D_{90} - D_{10}):	288.2	1.625
(D_{75} / D_{25}):	2.002	1.634
(D_{75} - D_{25}):	167.3	1.002

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.2%
SAND:	100.0%	MEDIUM SAND:	42.7%
MUD:	0.0%	FINE SAND:	55.1%
		V FINE SAND:	2.0%
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 ($\bar{x}$):	266.8	235.0	2.089	236.2	2.082	Fine Sand
SORTING (σ):	97.62	1.449	0.535	1.539	0.622	Moderately Well Sorted
SKEWNESS (Sk):	0.418	0.009	-0.009	0.106	-0.106	Coarse Skewed
KURTOSIS (K):	2.284	1.934	1.934	0.750	0.750	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **RB 4**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

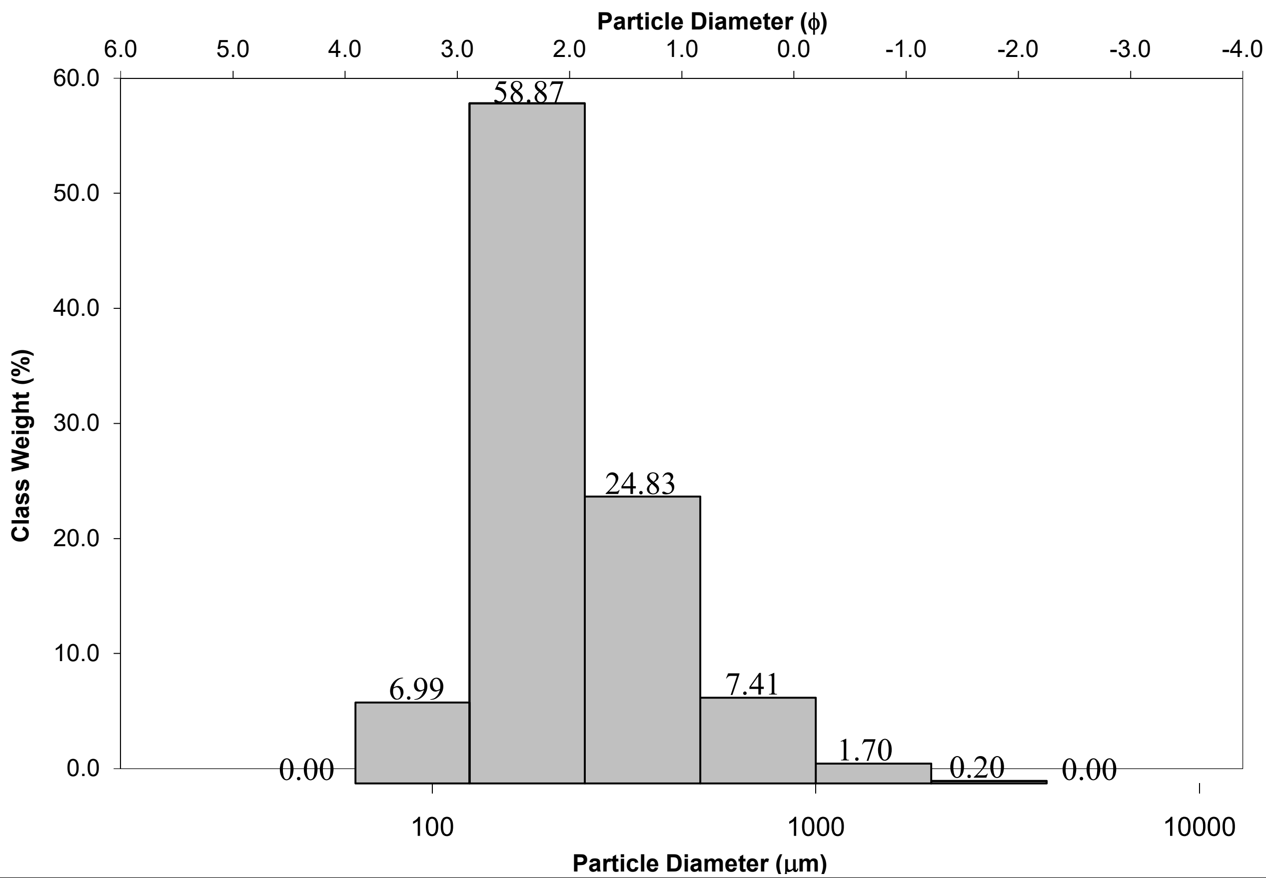
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	129.6	1.027
MEDIAN or D_{50}:	207.5	2.269
D_{90}:	490.6	2.948
(D_{90} / D_{10}):	3.785	2.869
$(D_{90} - D_{10})$:	361.0	1.920
(D_{75} / D_{25}):	2.088	1.651
$(D_{75} - D_{25})$:	168.2	1.062

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.2%	COARSE SAND:	7.4%
SAND:	99.8%	MEDIUM SAND:	24.8%
MUD:	0.0%	FINE SAND:	58.9%
		V FINE SAND:	6.9%
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:	0.2%	V FINE SILT:	0.0%
V COARSE SAND:	1.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	297.3	231.2	2.113	228.8	2.128	Fine Sand
SORTING (σ):	256.8	1.748	0.806	1.774	0.827	Moderately Sorted
SKEWNESS (Sk):	4.420	1.052	-1.052	0.282	-0.282	Coarse Skewed
KURTOSIS (K):	33.56	4.600	4.600	1.102	1.102	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **RB 5**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Medium Sand

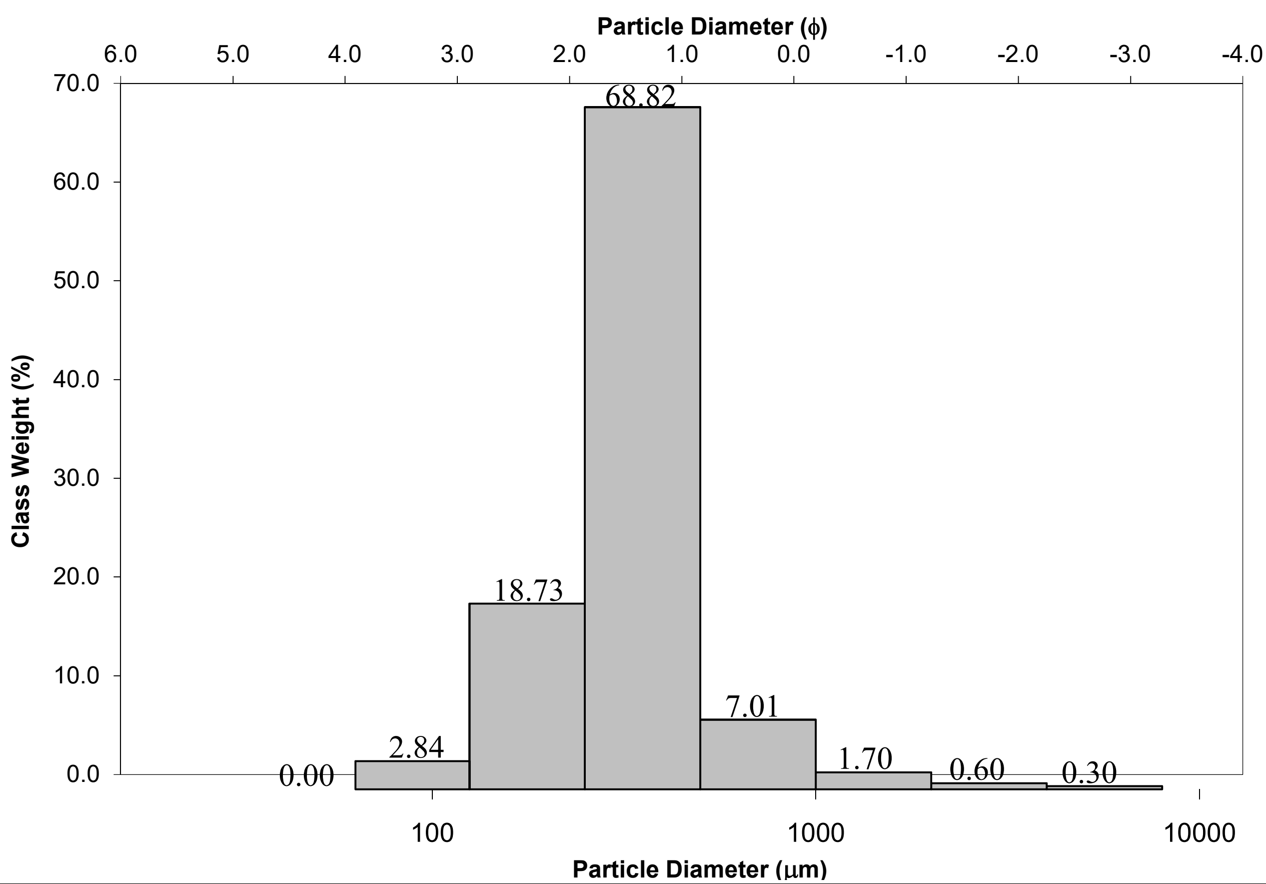
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	163.1	1.006
MEDIAN or D_{50}:	333.0	1.587
D_{90}:	498.1	2.616
(D_{90} / D_{10}):	3.054	2.602
$(D_{90} - D_{10})$:	335.0	1.611
(D_{75} / D_{25}):	1.654	1.594
$(D_{75} - D_{25})$:	169.4	0.726

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.9%	COARSE SAND:	7.0%
SAND:	99.1%	MEDIUM SAND:	68.8%
MUD:	0.0%	FINE SAND:	18.7%
		V FINE SAND:	2.8%
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:	0.3%	FINE SILT:	0.0%
V FINE GRAVEL:	0.6%	V FINE SILT:	0.0%
V COARSE SAND:	1.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	410.1	327.8	1.609	316.8	1.658	Medium Sand
SORTING (σ):	419.0	1.654	0.726	1.609	0.686	Moderately Well Sorted
SKEWNESS (Sk):	8.856	0.849	-0.849	-0.100	0.100	Symmetrical
KURTOSIS (K):	104.9	8.388	8.388	1.434	1.434	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **RB 6**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

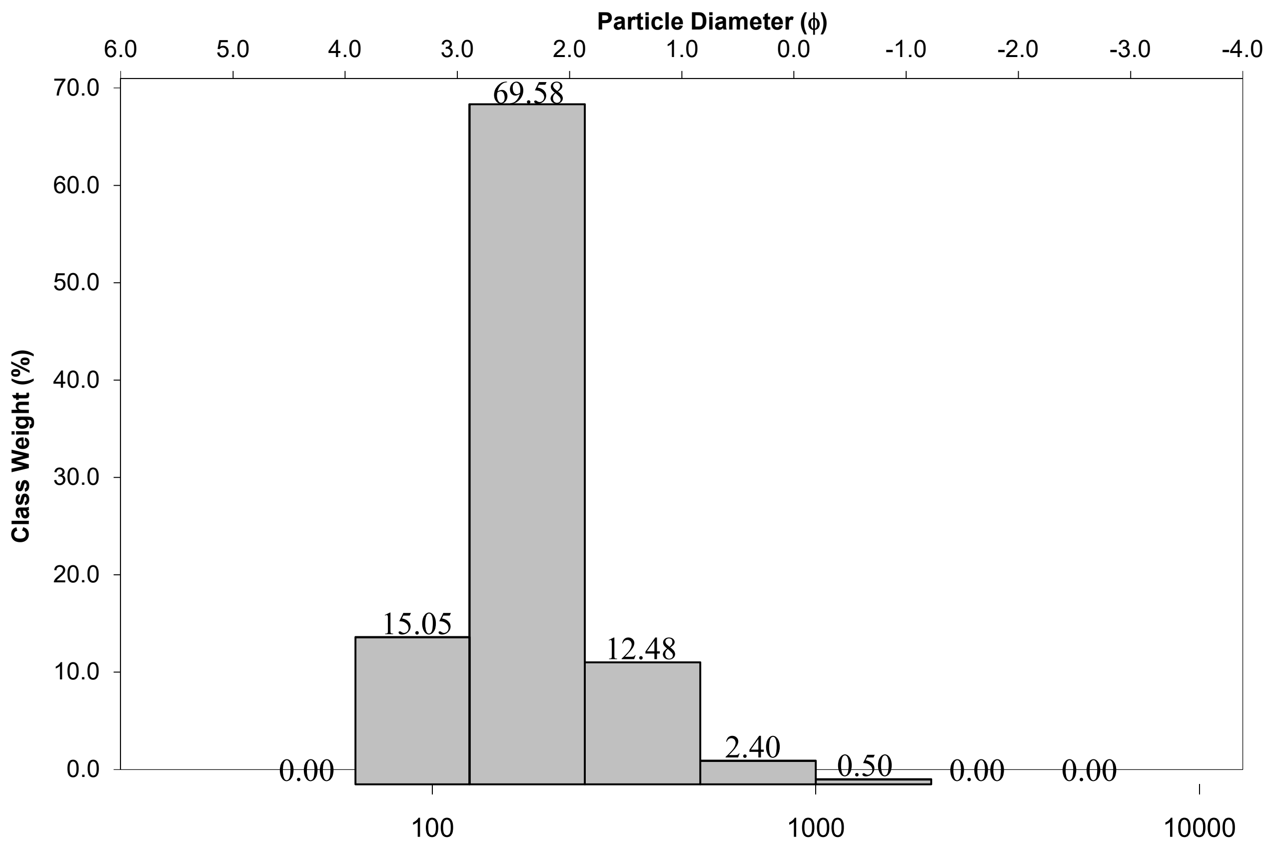
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	99.78	1.568
MEDIAN or D_{50}:	177.2	2.496
D_{90}:	337.3	3.325
(D_{90} / D_{10}):	3.380	2.121
$(D_{90} - D_{10})$:	237.5	1.757
(D_{75} / D_{25}):	1.644	1.336
$(D_{75} - D_{25})$:	89.03	0.717

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	2.4%
SAND:	100.0%	MEDIUM SAND:	12.5%
MUD:	0.0%	FINE SAND:	69.7%
		V FINE SAND:	14.9%
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:	0.0%	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 ($\bar{x}$):	217.1	181.7	2.460	177.2	2.496	Fine Sand
SORTING (σ):	145.0	1.560	0.642	1.538	0.621	Moderately Well Sorted
SKEWNESS (Sk):	4.718	0.970	-0.970	0.034	-0.034	Symmetrical
KURTOSIS (K):	35.26	5.987	5.987	1.422	1.422	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **RB 7**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

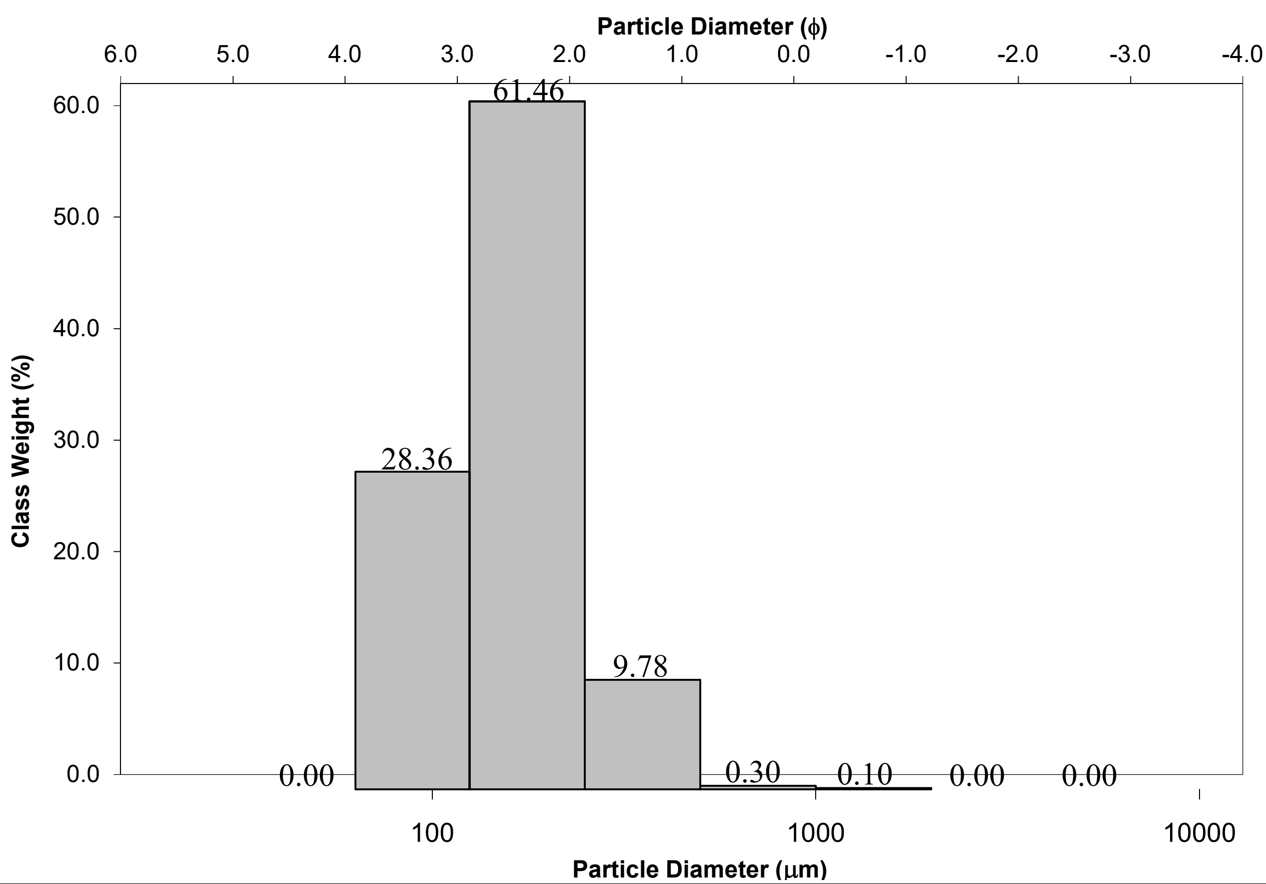
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	80.38	1.979
MEDIAN or D_{50}:	159.8	2.645
D_{90}:	253.7	3.637
(D_{90} / D_{10}):	3.157	1.838
$(D_{90} - D_{10})$:	173.4	1.659
(D_{75} / D_{25}):	1.828	1.388
$(D_{75} - D_{25})$:	95.88	0.870

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.3%
SAND:	100.0%	MEDIUM SAND:	9.8%
MUD:	0.0%	FINE SAND:	61.7%
		V FINE SAND:	28.1%
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 ($\bar{x}$):	182.6	156.8	2.673	151.6	2.722	Fine Sand
SORTING (σ):	92.51	1.522	0.606	1.611	0.688	Moderately Well Sorted
SKEWNESS (Sk):	4.219	0.305	-0.305	-0.084	0.084	Symmetrical
KURTOSIS (K):	47.49	3.575	3.575	1.104	1.104	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **RB 8**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

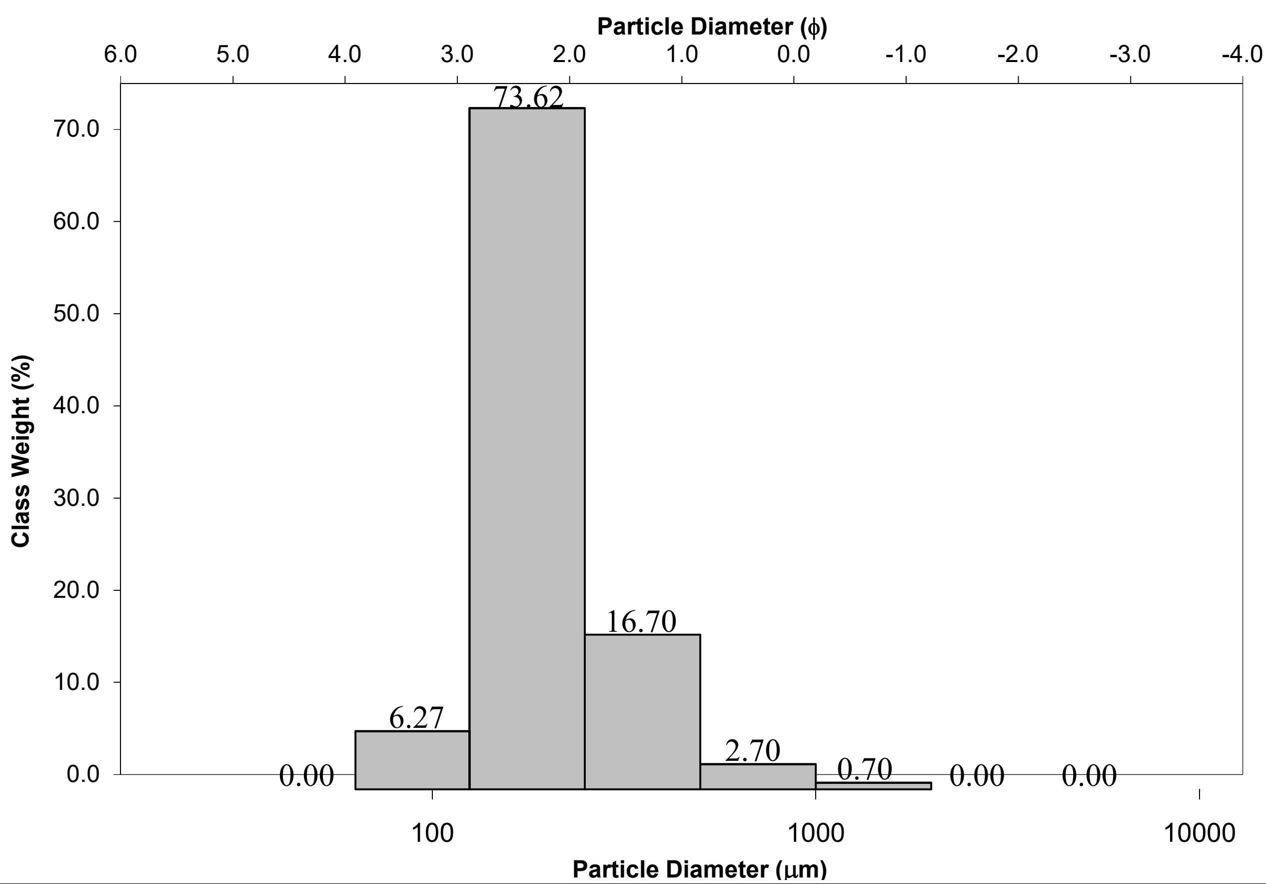
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	129.5	1.395
MEDIAN or D_{50}:	188.7	2.406
D_{90}:	380.3	2.949
(D_{90} / D_{10}):	2.936	2.114
$(D_{90} - D_{10})$:	250.8	1.554
(D_{75} / D_{25}):	1.601	1.328
$(D_{75} - D_{25})$:	89.60	0.679

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	2.7%
SAND:	100.0%	MEDIUM SAND:	16.7%
MUD:	0.0%	FINE SAND:	73.7%
		V FINE SAND:	6.2%
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:	0.0%	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 ($\bar{x}$):	237.4	200.3	2.319	197.2	2.342	Fine Sand
SORTING (σ):	156.7	1.522	0.606	1.512	0.596	Moderately Well Sorted
SKEWNESS (Sk):	4.655	1.380	-1.380	0.210	-0.210	Coarse Skewed
KURTOSIS (K):	32.79	6.926	6.926	1.266	1.266	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **RB 9**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

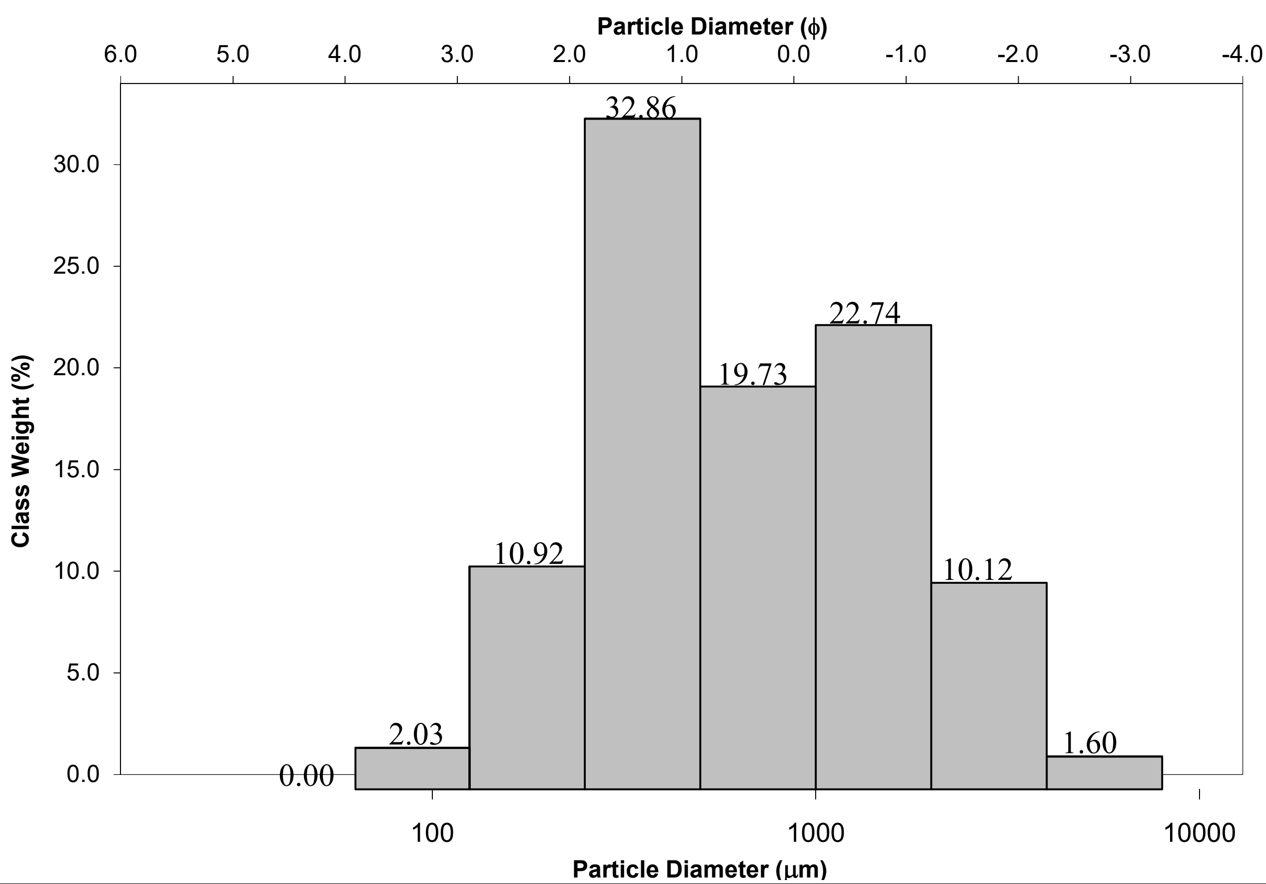
SEDIMENT NAME: Very Fine Gravelly Medium Sand

	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:	1500.0	-0.500
MODE 3:		
D_{10}:	207.6	-1.170
MEDIAN or D_{50}:	579.6	0.787
D_{90}:	2250.6	2.268
(D_{90} / D_{10}):	10.84	-1.938
$(D_{90} - D_{10})$:	2042.9	3.438
(D_{75} / D_{25}):	4.138	-3.922
$(D_{75} - D_{25})$:	1012.0	2.049

GRAIN SIZE DISTRIBUTION			
GRAVEL:	11.7%	COARSE SAND:	19.7%
SAND:	88.3%	MEDIUM SAND:	32.9%
MUD:	0.0%	FINE SAND:	10.9%
		V FINE SAND:	2.0%
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:	1.6%	FINE SILT:	0.0%
V FINE GRAVEL:	10.1%	V FINE SILT:	0.0%
V COARSE SAND:	22.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1034.6	646.6	0.629	647.5	0.627	Coarse Sand
SORTING (σ):	1044.3	2.472	1.306	2.540	1.345	Poorly Sorted
SKEWNESS (Sk):	2.258	0.176	-0.176	0.146	-0.146	Coarse Skewed
KURTOSIS (K):	9.587	2.361	2.361	0.878	0.878	Platykurtic

GRAIN SIZE DISTRIBUTION



ANEXO II

Great Sister Basin

Results of Grain Size Analysis

SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **109**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

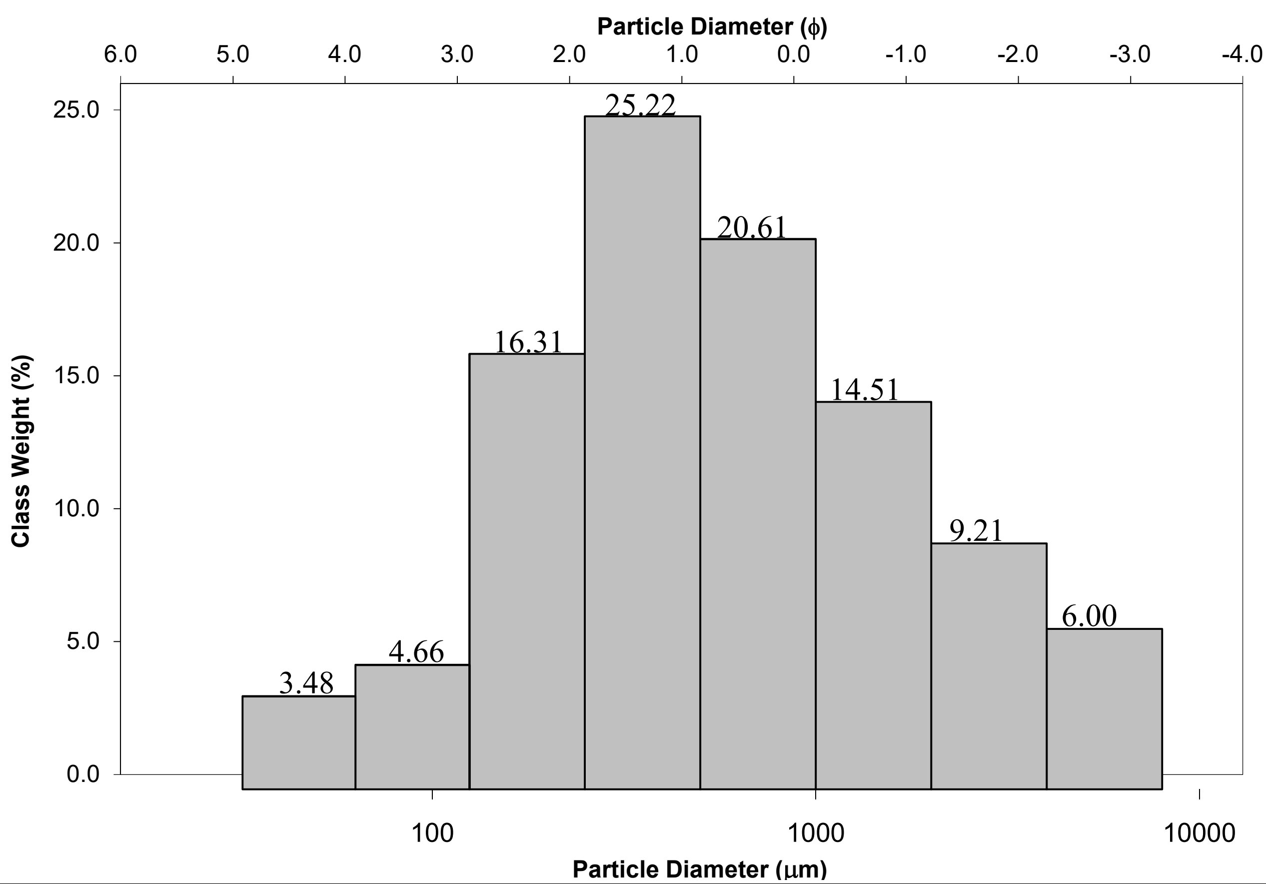
	μm	φ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	136.0	-1.567
MEDIAN or D_{50}:	506.8	0.981
D_{90}:	2963.7	2.879
(D_{90} / D_{10}):	21.79	-1.837
$(D_{90} - D_{10})$:	2827.7	4.446
(D_{75} / D_{25}):	4.931	-6.027
$(D_{75} - D_{25})$:	1000.4	2.302

GRAIN SIZE DISTRIBUTION

GRAVEL:	15.2%	COARSE SAND:	20.6%
SAND:	81.4%	MEDIUM SAND:	25.3%
MUD:	3.4%	FINE SAND:	16.3%
		V FINE SAND:	4.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.4%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	6.0%	FINE SILT:	0.0%
V FINE GRAVEL:	9.2%	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 ($\bar{x}$):	1141.3	557.6	0.843	555.5	0.848	Coarse Sand
SORTING (σ):	1475.2	3.187	1.672	3.353	1.746	Poorly Sorted
SKEWNESS (Sk):	2.221	0.103	-0.103	0.099	-0.099	Symmetrical
KURTOSIS (K):	7.377	2.592	2.592	1.035	1.035	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **110**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

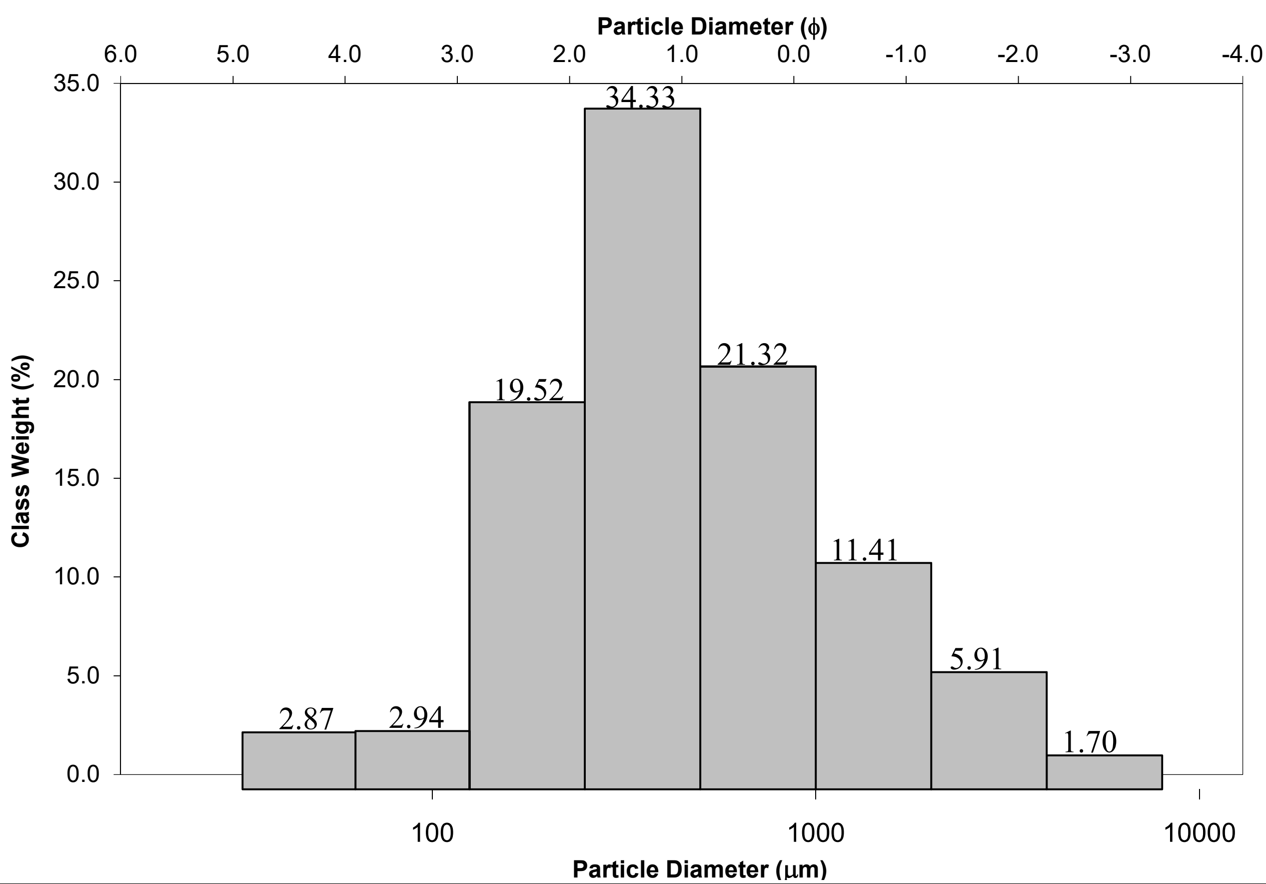
	μm	φ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	145.5	-0.791
MEDIAN or D_{50}:	411.8	1.280
D_{90}:	1730.5	2.781
(D_{90} / D_{10}):	11.89	-3.514
$(D_{90} - D_{10})$:	1585.0	3.572
(D_{75} / D_{25}):	3.325	7.206
$(D_{75} - D_{25})$:	576.2	1.733

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.6%	COARSE SAND:	21.3%
SAND:	89.6%	MEDIUM SAND:	34.4%
MUD:	2.8%	FINE SAND:	19.5%
		V FINE SAND:	2.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.7%	FINE SILT:	0.0%
V FINE GRAVEL:	5.9%	V FINE SILT:	0.0%
V COARSE SAND:	11.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	780.6	450.8	1.149	446.8	1.162	Medium Sand
SORTING (σ):	984.2	2.607	1.383	2.629	1.395	Poorly Sorted
SKEWNESS (Sk):	3.175	0.225	-0.225	0.145	-0.145	Coarse Skewed
KURTOSIS (K):	15.09	3.227	3.227	1.108	1.108	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **111**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Fine Gravelly Medium Sand

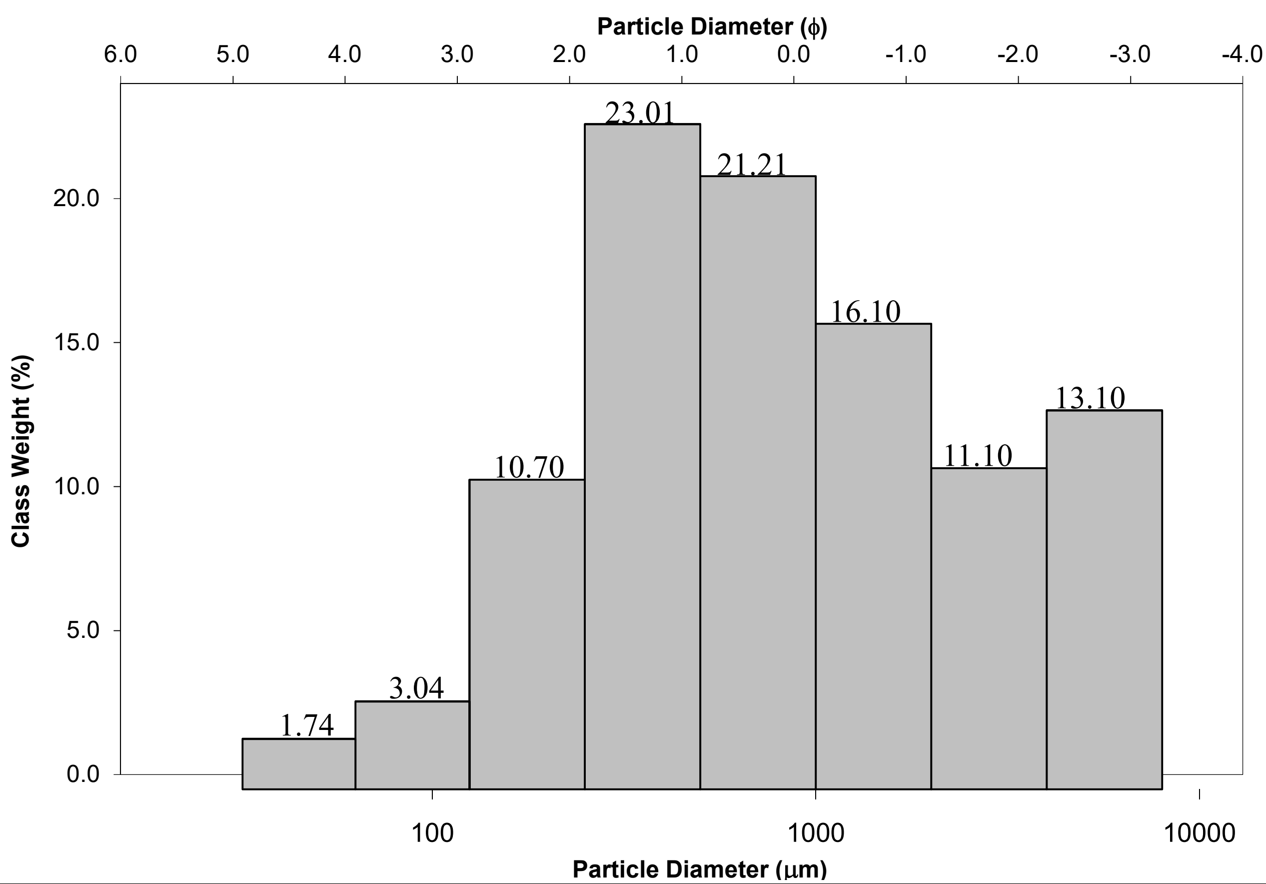
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	176.1	-2.237
MEDIAN or D_{50}:	729.4	0.455
D_{90}:	4715.5	2.506
(D_{90} / D_{10}):	26.78	-1.120
$(D_{90} - D_{10})$:	4539.4	4.743
(D_{75} / D_{25}):	5.798	-1.664
$(D_{75} - D_{25})$:	1600.7	2.536

GRAIN SIZE DISTRIBUTION

GRAVEL:	24.2%	COARSE SAND:	21.2%
SAND:	74.1%	MEDIUM SAND:	23.0%
MUD:	1.7%	FINE SAND:	10.7%
		V FINE SAND:	3.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.7%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	13.1%	FINE SILT:	0.0%
V FINE GRAVEL:	11.1%	V FINE SILT:	0.0%
V COARSE SAND:	16.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1631.1	798.2	0.325	852.7	0.230	Coarse Sand
SORTING (σ):	1891.8	3.290	1.718	3.424	1.776	Poorly Sorted
SKEWNESS (Sk):	1.495	0.015	-0.015	0.141	-0.141	Coarse Skewed
KURTOSIS (K):	3.873	2.361	2.361	0.904	0.904	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **112**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

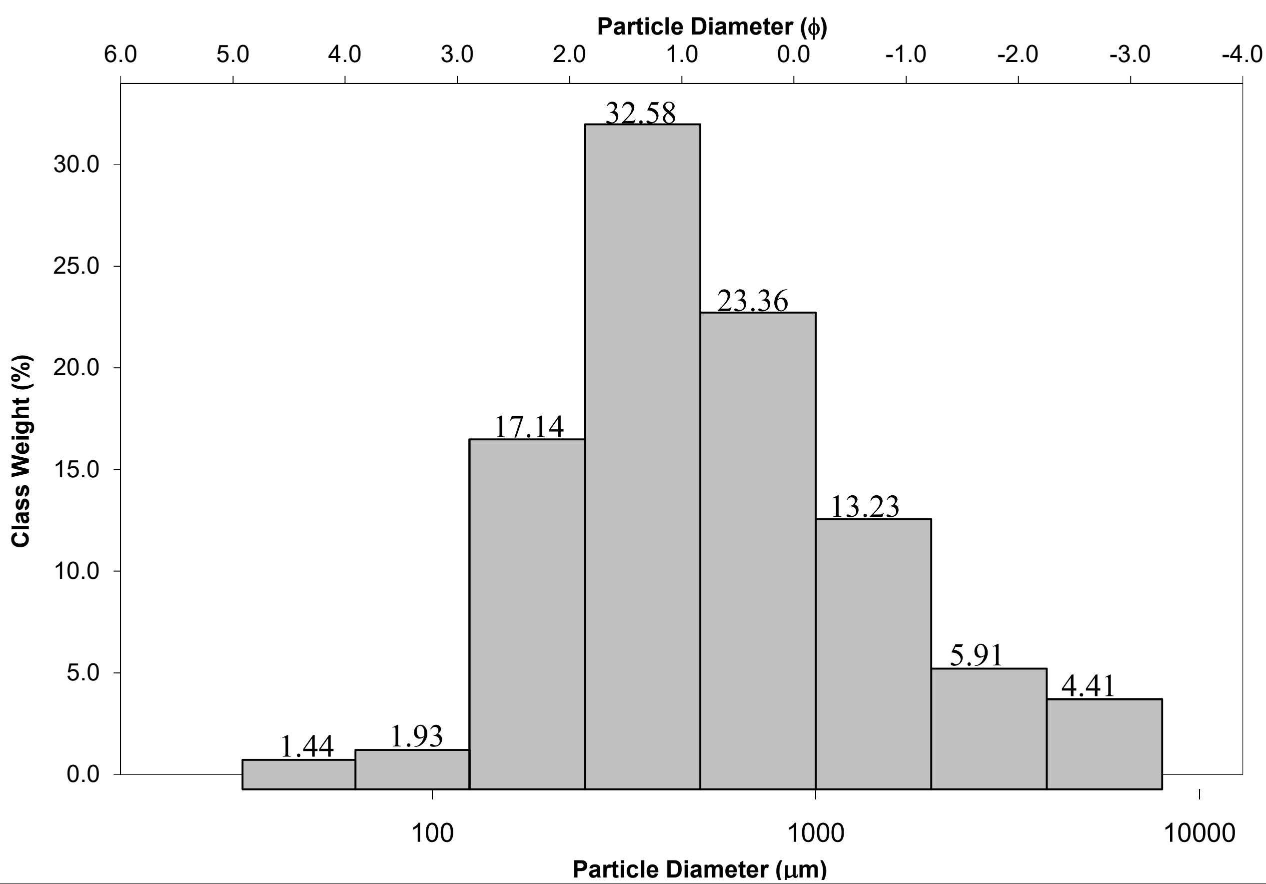
	μm	φ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	163.8	-1.056
MEDIAN or D_{50}:	468.5	1.094
D_{90}:	2079.1	2.610
(D_{90} / D_{10}):	12.69	-2.472
$(D_{90} - D_{10})$:	1915.3	3.666
(D_{75} / D_{25}):	3.481	30.43
$(D_{75} - D_{25})$:	683.2	1.800

GRAIN SIZE DISTRIBUTION

GRAVEL:	10.3%	COARSE SAND:	23.4%
SAND:	88.3%	MEDIUM SAND:	32.6%
MUD:	1.4%	FINE SAND:	17.2%
		V FINE SAND:	1.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.4%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	4.4%	FINE SILT:	0.0%
V FINE GRAVEL:	5.9%	V FINE SILT:	0.0%
V COARSE SAND:	13.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	973.1	536.3	0.899	525.8	0.927	Coarse Sand
SORTING (σ):	1286.8	2.673	1.419	2.705	1.436	Poorly Sorted
SKEWNESS (Sk):	2.787	0.412	-0.412	0.212	-0.212	Coarse Skewed
KURTOSIS (K):	10.69	3.136	3.136	1.094	1.094	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **113**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

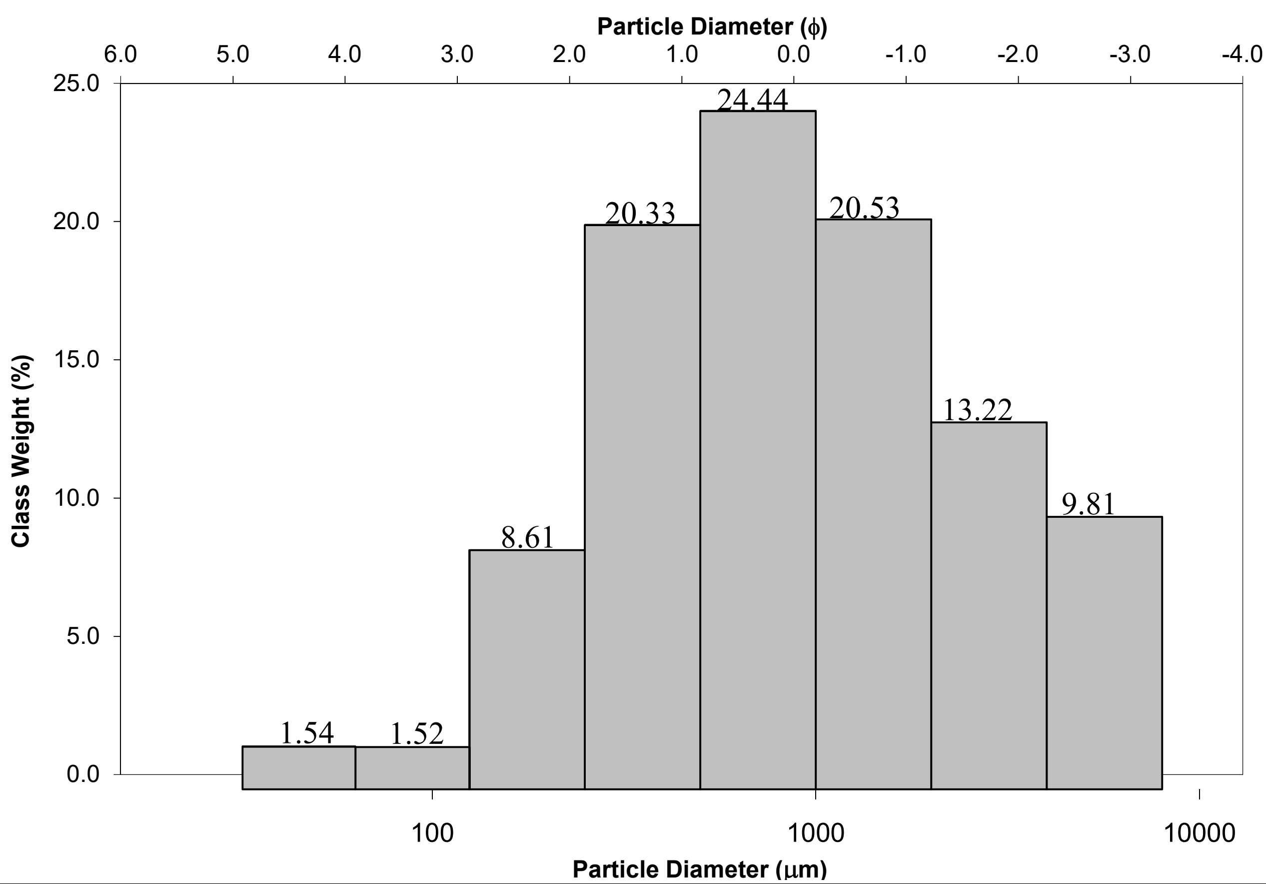
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	219.4	-1.986
MEDIAN or D_{50}:	833.8	0.262
D_{90}:	3962.4	2.188
(D_{90} / D_{10}):	18.06	-1.102
(D_{90} - D_{10}):	3743.0	4.175
(D_{75} / D_{25}):	4.748	-1.483
(D_{75} - D_{25}):	1478.0	2.247

GRAIN SIZE DISTRIBUTION

GRAVEL:	23.0%	COARSE SAND:	24.4%
SAND:	75.5%	MEDIUM SAND:	20.3%
MUD:	1.5%	FINE SAND:	8.6%
		V FINE SAND:	1.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.5%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	9.8%	FINE SILT:	0.0%
V FINE GRAVEL:	13.2%	V FINE SILT:	0.0%
V COARSE SAND:	20.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1572.0	860.9	0.216	887.9	0.171	Coarse Sand
SORTING (σ):	1698.7	2.965	1.568	3.087	1.626	Poorly Sorted
SKEWNESS (Sk):	1.651	-0.115	0.115	0.065	-0.065	Symmetrical
KURTOSIS (K):	4.719	2.670	2.670	0.959	0.959	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **209**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

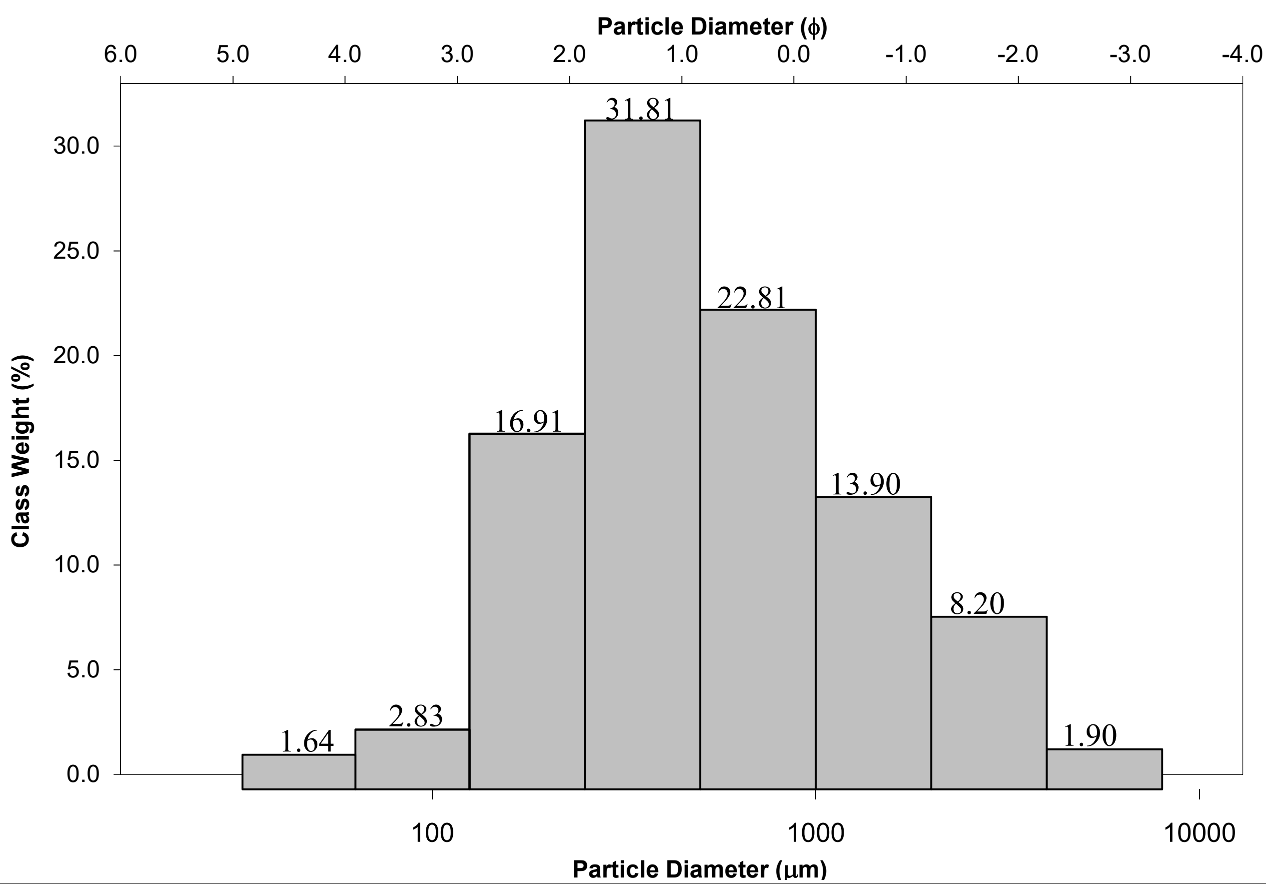
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	157.2	-1.013
MEDIAN or D_{50}:	466.8	1.099
D_{90}:	2018.7	2.669
(D_{90} / D_{10}):	12.84	-2.634
$(D_{90} - D_{10})$:	1861.5	3.683
(D_{75} / D_{25}):	3.584	44.07
$(D_{75} - D_{25})$:	699.9	1.842

GRAIN SIZE DISTRIBUTION

GRAVEL:	10.1%	COARSE SAND:	22.8%
SAND:	88.3%	MEDIUM SAND:	31.8%
MUD:	1.6%	FINE SAND:	16.9%
		V FINE SAND:	2.8%
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:	1.9%	FINE SILT:	0.0%
V FINE GRAVEL:	8.2%	V FINE SILT:	0.0%
V COARSE SAND:	13.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	894.7	519.8	0.944	519.2	0.946	Coarse Sand
SORTING (σ):	1056.1	2.627	1.393	2.672	1.418	Poorly Sorted
SKEWNESS (Sk):	2.715	0.203	-0.203	0.173	-0.173	Coarse Skewed
KURTOSIS (K):	11.77	2.898	2.898	1.021	1.021	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **210**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

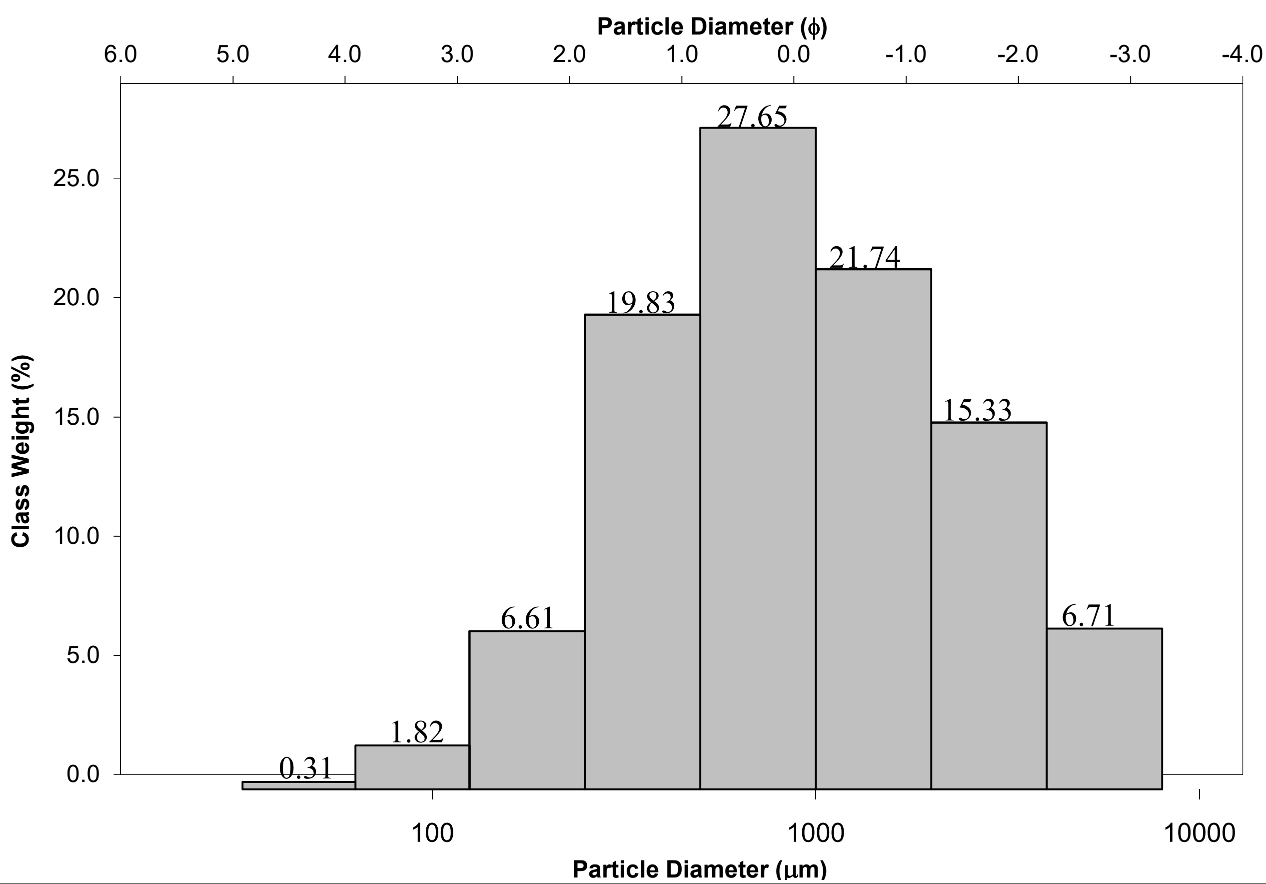
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	261.5	-1.786
MEDIAN or D_{50}:	855.8	0.225
D_{90}:	3447.7	1.935
(D_{90} / D_{10}):	13.19	-1.084
$(D_{90} - D_{10})$:	3186.2	3.721
(D_{75} / D_{25}):	4.122	-1.365
$(D_{75} - D_{25})$:	1378.6	2.043

GRAIN SIZE DISTRIBUTION

GRAVEL:	22.0%	COARSE SAND:	27.7%
SAND:	77.7%	MEDIUM SAND:	19.8%
MUD:	0.3%	FINE SAND:	6.6%
		V FINE SAND:	1.8%
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:	6.7%	FINE SILT:	0.0%
V FINE GRAVEL:	15.3%	V FINE SILT:	0.0%
V COARSE SAND:	21.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1484.9	888.1	0.171	898.5	0.154	Coarse Sand
SORTING (σ):	1505.6	2.664	1.414	2.802	1.487	Poorly Sorted
SKEWNESS (Sk):	1.796	-0.054	0.054	0.050	-0.050	Symmetrical
KURTOSIS (K):	5.714	2.617	2.617	0.966	0.966	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **211** ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Fine Gravelly Coarse Sand

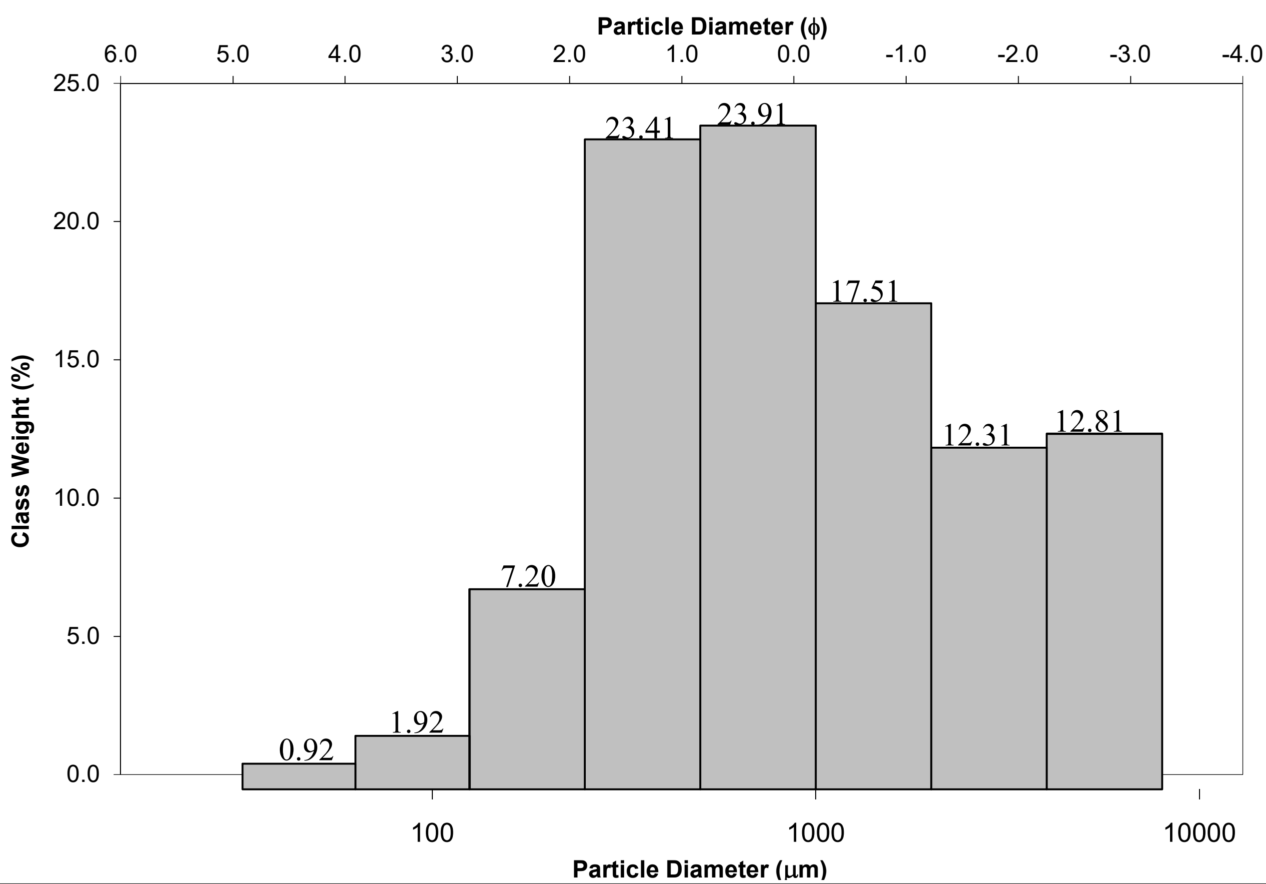
	μm	φ
MODE 1:	750.0	0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	249.8	-2.220
MEDIAN or D_{50}:	808.0	0.308
D_{90}:	4657.4	2.001
(D_{90} / D_{10}):	18.65	-0.902
$(D_{90} - D_{10})$:	4407.7	4.221
(D_{75} / D_{25}):	5.170	-1.346
$(D_{75} - D_{25})$:	1624.6	2.370

GRAIN SIZE DISTRIBUTION

GRAVEL:	25.1%	COARSE SAND:	23.9%
SAND:	74.0%	MEDIUM SAND:	23.4%
MUD:	0.9%	FINE SAND:	7.2%
		V FINE SAND:	1.9%
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:	12.8%	FINE SILT:	0.0%
V FINE GRAVEL:	12.3%	V FINE SILT:	0.0%
V COARSE SAND:	17.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1683.9	891.7	0.165	930.7	0.104	Coarse Sand
SORTING (σ):	1857.3	3.021	1.595	3.193	1.675	Poorly Sorted
SKEWNESS (Sk):	1.483	0.034	-0.034	0.138	-0.138	Coarse Skewed
KURTOSIS (K):	3.887	2.438	2.438	0.917	0.917	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **212**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

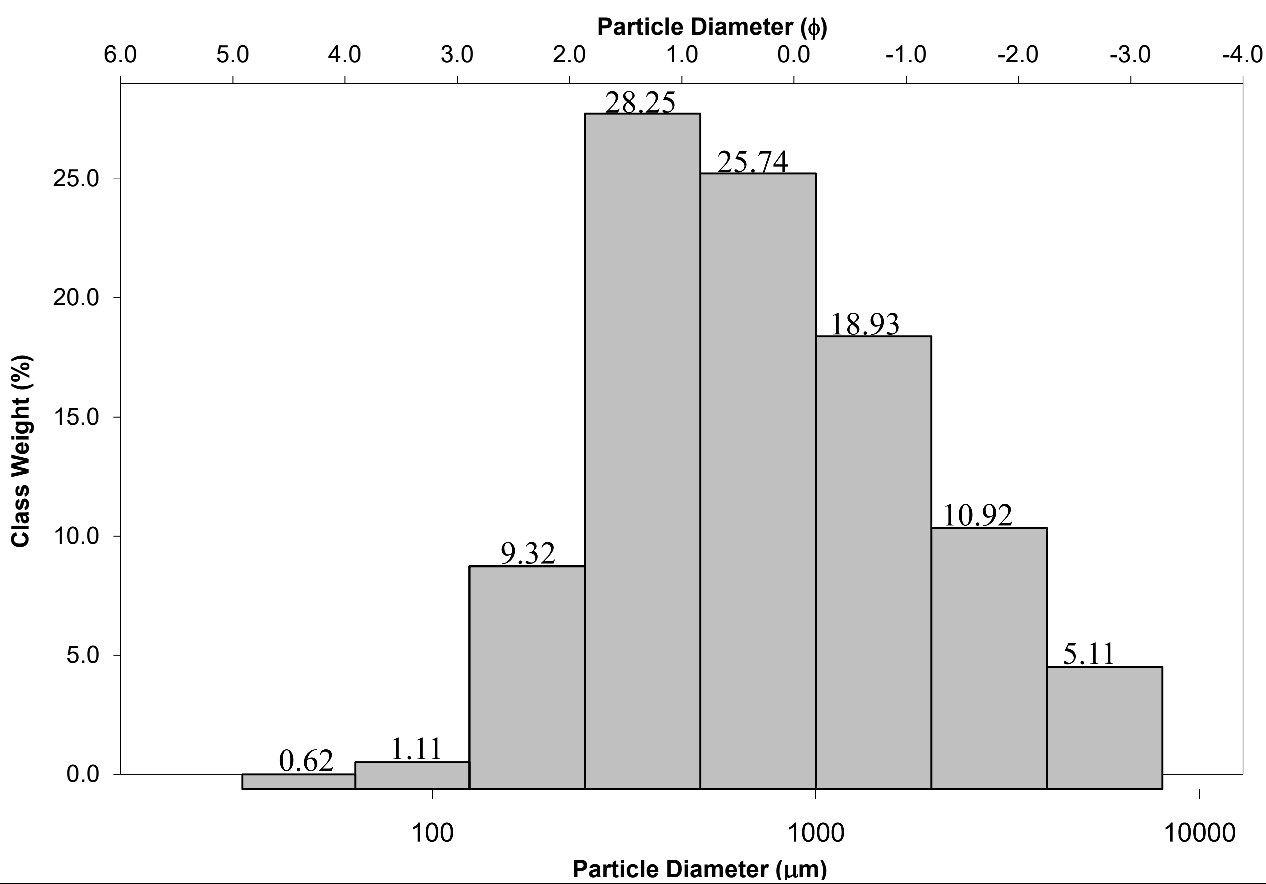
	μm	φ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	231.7	-1.552
MEDIAN or D_{50}:	667.3	0.584
D_{90}:	2932.8	2.110
(D_{90} / D_{10}):	12.66	-1.359
$(D_{90} - D_{10})$:	2701.1	3.662
(D_{75} / D_{25}):	4.089	-2.859
$(D_{75} - D_{25})$:	1088.1	2.032

GRAIN SIZE DISTRIBUTION

GRAVEL:	16.0%	COARSE SAND:	25.8%
SAND:	83.4%	MEDIUM SAND:	28.3%
MUD:	0.6%	FINE SAND:	9.3%
		V FINE SAND:	1.1%
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:	5.1%	FINE SILT:	0.0%
V FINE GRAVEL:	10.9%	V FINE SILT:	0.0%
V COARSE SAND:	18.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1236.2	724.6	0.465	722.9	0.468	Coarse Sand
SORTING (σ):	1381.5	2.622	1.391	2.665	1.414	Poorly Sorted
SKEWNESS (Sk):	2.194	0.199	-0.199	0.119	-0.119	Coarse Skewed
KURTOSIS (K):	7.602	2.713	2.713	0.942	0.942	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **213**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Fine Gravelly Coarse Sand

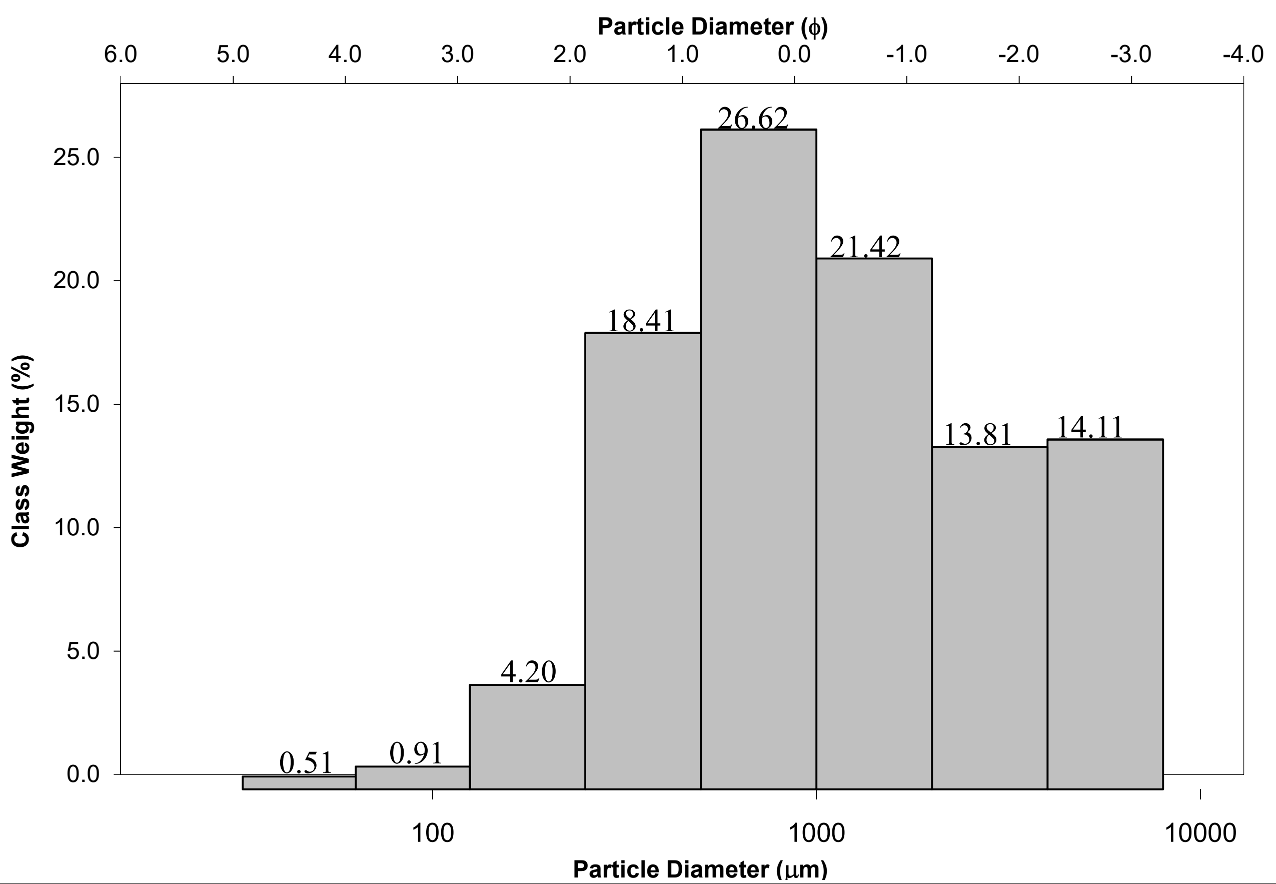
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	295.0	-2.291
MEDIAN or D_{50}:	983.2	0.024
D_{90}:	4895.6	1.761
(D_{90} / D_{10}):	16.60	-0.769
$(D_{90} - D_{10})$:	4600.7	4.053
(D_{75} / D_{25}):	4.517	-0.795
$(D_{75} - D_{25})$:	1803.6	2.175

GRAIN SIZE DISTRIBUTION

GRAVEL:	27.9%	COARSE SAND:	26.6%
SAND:	71.6%	MEDIUM SAND:	18.4%
MUD:	0.5%	FINE SAND:	4.2%
		V FINE SAND:	0.9%
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:	14.1%	FINE SILT:	0.0%
V FINE GRAVEL:	13.8%	V FINE SILT:	0.0%
V COARSE SAND:	21.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1860.3	1070.9	-0.099	1097.7	-0.134	Very Coarse Sand
SORTING (σ):	1876.9	2.790	1.480	2.929	1.551	Poorly Sorted
SKEWNESS (Sk):	1.356	-0.030	0.030	0.130	-0.130	Coarse Skewed
KURTOSIS (K):	3.502	2.517	2.517	0.902	0.902	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **214**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

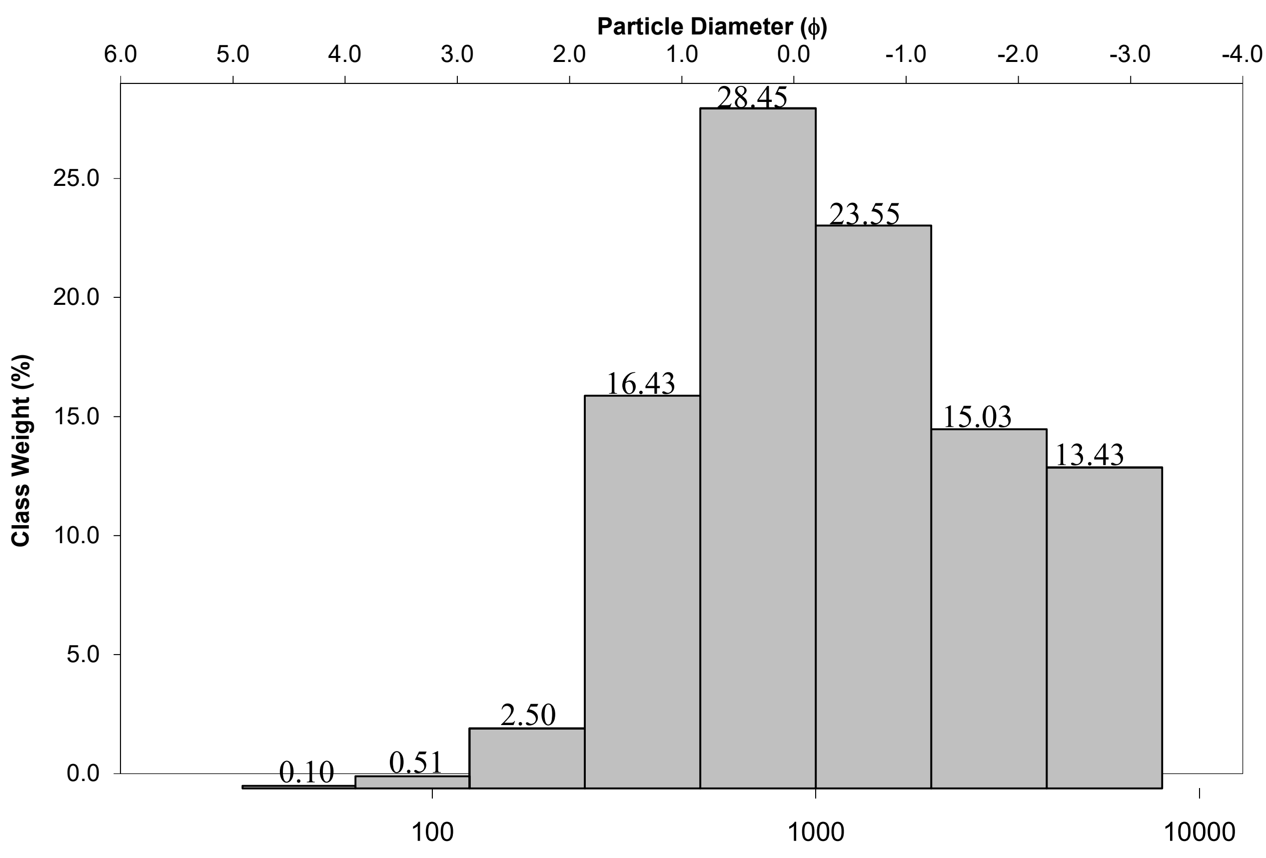
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	334.4	-2.255
MEDIAN or D_{50}:	1060.8	-0.085
D_{90}:	4774.1	1.580
(D_{90} / D_{10}):	14.28	-0.701
(D_{90} - D_{10}):	4439.7	3.836
(D_{75} / D_{25}):	4.107	-0.657
(D_{75} - D_{25}):	1774.5	2.038

GRAIN SIZE DISTRIBUTION

GRAVEL:	28.5%	COARSE SAND:	28.5%
SAND:	71.4%	MEDIUM SAND:	16.4%
MUD:	0.1%	FINE SAND:	2.5%
		V FINE SAND:	0.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	13.4%	FINE SILT:	0.0%
V FINE GRAVEL:	15.0%	V FINE SILT:	0.0%
V COARSE SAND:	23.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1890.0	1153.1	-0.205	1175.2	-0.233	Very Coarse Sand
SORTING (σ):	1824.3	2.582	1.368	2.722	1.445	Poorly Sorted
SKEWNESS (Sk):	1.377	0.073	-0.073	0.136	-0.136	Coarse Skewed
KURTOSIS (K):	3.626	2.386	2.386	0.907	0.907	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **309**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

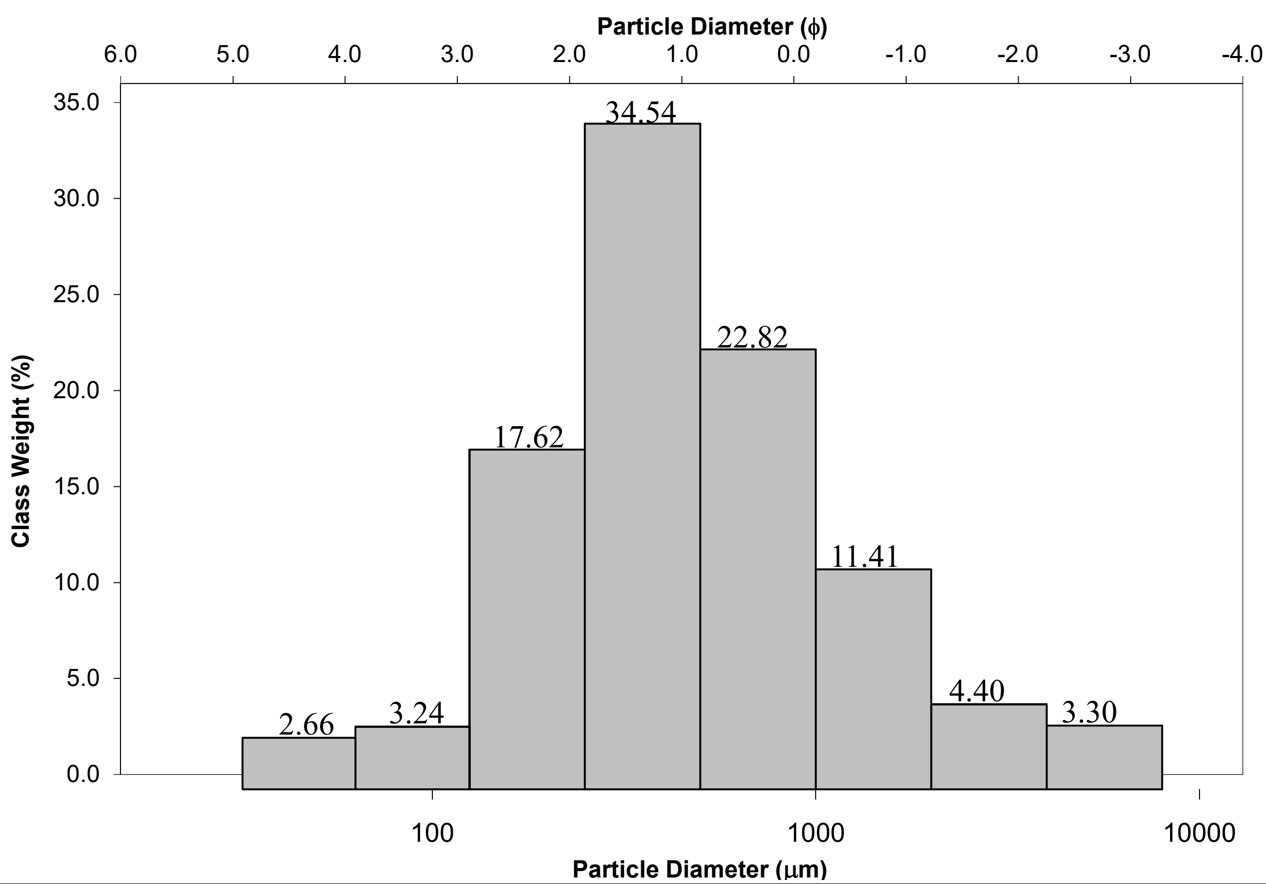
	μm	φ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	147.4	-0.800
MEDIAN or D_{50}:	425.8	1.232
D_{90}:	1741.1	2.763
(D_{90} / D_{10}):	11.81	-3.453
$(D_{90} - D_{10})$:	1593.7	3.563
(D_{75} / D_{25}):	3.246	7.620
$(D_{75} - D_{25})$:	579.2	1.698

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.7%	COARSE SAND:	22.8%
SAND:	89.7%	MEDIUM SAND:	34.6%
MUD:	2.6%	FINE SAND:	17.6%
		V FINE SAND:	3.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	3.3%	FINE SILT:	0.0%
V FINE GRAVEL:	4.4%	V FINE SILT:	0.0%
V COARSE SAND:	11.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	840.3	467.7	1.096	458.0	1.126	Medium Sand
SORTING (σ):	1149.7	2.654	1.408	2.660	1.412	Poorly Sorted
SKEWNESS (Sk):	3.230	0.309	-0.309	0.144	-0.144	Coarse Skewed
KURTOSIS (K):	14.02	3.423	3.423	1.174	1.174	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **310** ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

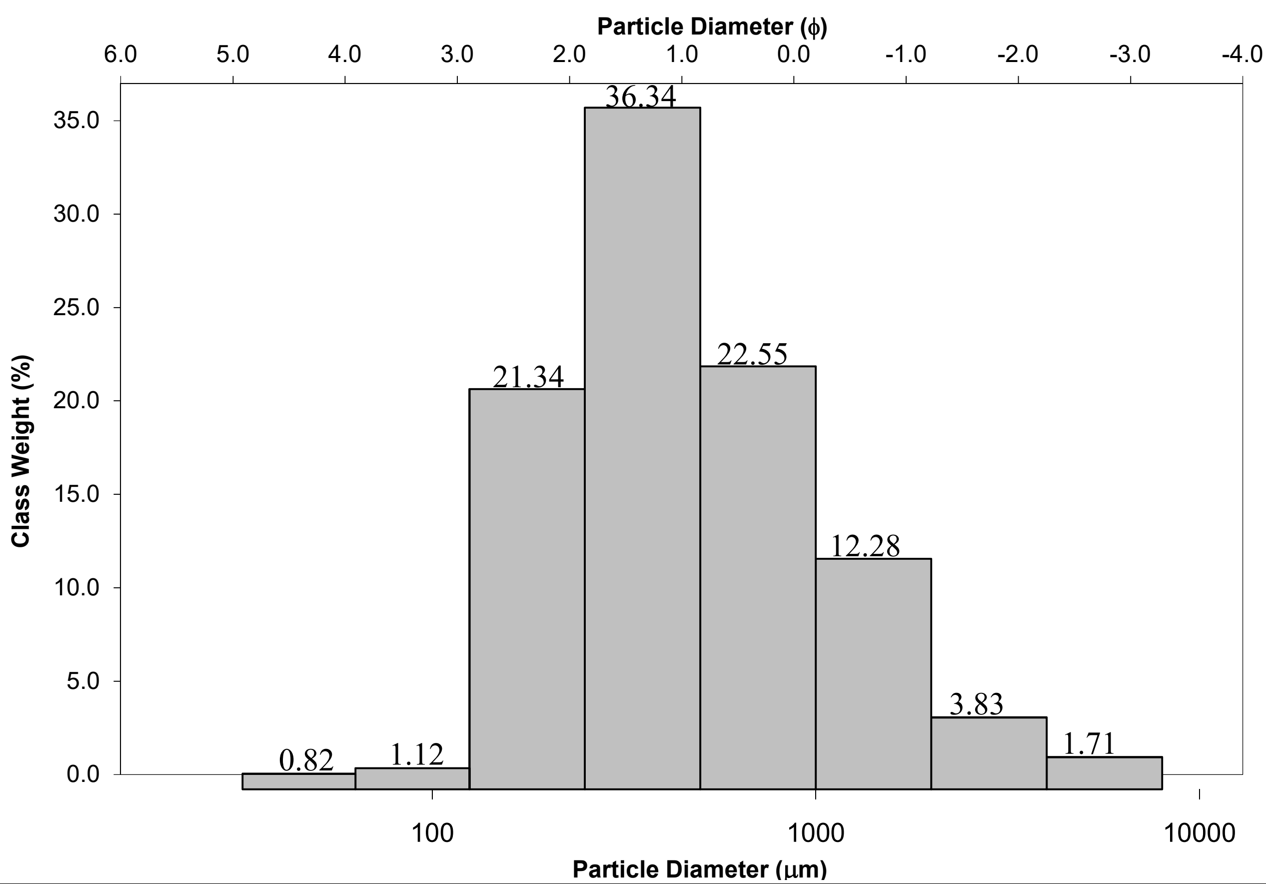
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	162.5	-0.637
MEDIAN or D_{50}:	416.2	1.265
D_{90}:	1555.0	2.621
(D_{90} / D_{10}):	9.567	-4.116
$(D_{90} - D_{10})$:	1392.4	3.258
(D_{75} / D_{25}):	3.104	6.137
$(D_{75} - D_{25})$:	543.7	1.634

GRAIN SIZE DISTRIBUTION

GRAVEL:	5.5%	COARSE SAND:	22.6%
SAND:	93.7%	MEDIUM SAND:	36.4%
MUD:	0.8%	FINE SAND:	21.3%
		V FINE SAND:	1.1%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.7%	FINE SILT:	0.0%
V FINE GRAVEL:	3.8%	V FINE SILT:	0.0%
V COARSE SAND:	12.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	748.8	464.9	1.105	450.0	1.152	Medium Sand
SORTING (σ):	928.5	2.343	1.228	2.342	1.228	Poorly Sorted
SKEWNESS (Sk):	3.629	0.526	-0.526	0.170	-0.170	Coarse Skewed
KURTOSIS (K):	18.93	3.393	3.393	1.002	1.002	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **311**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

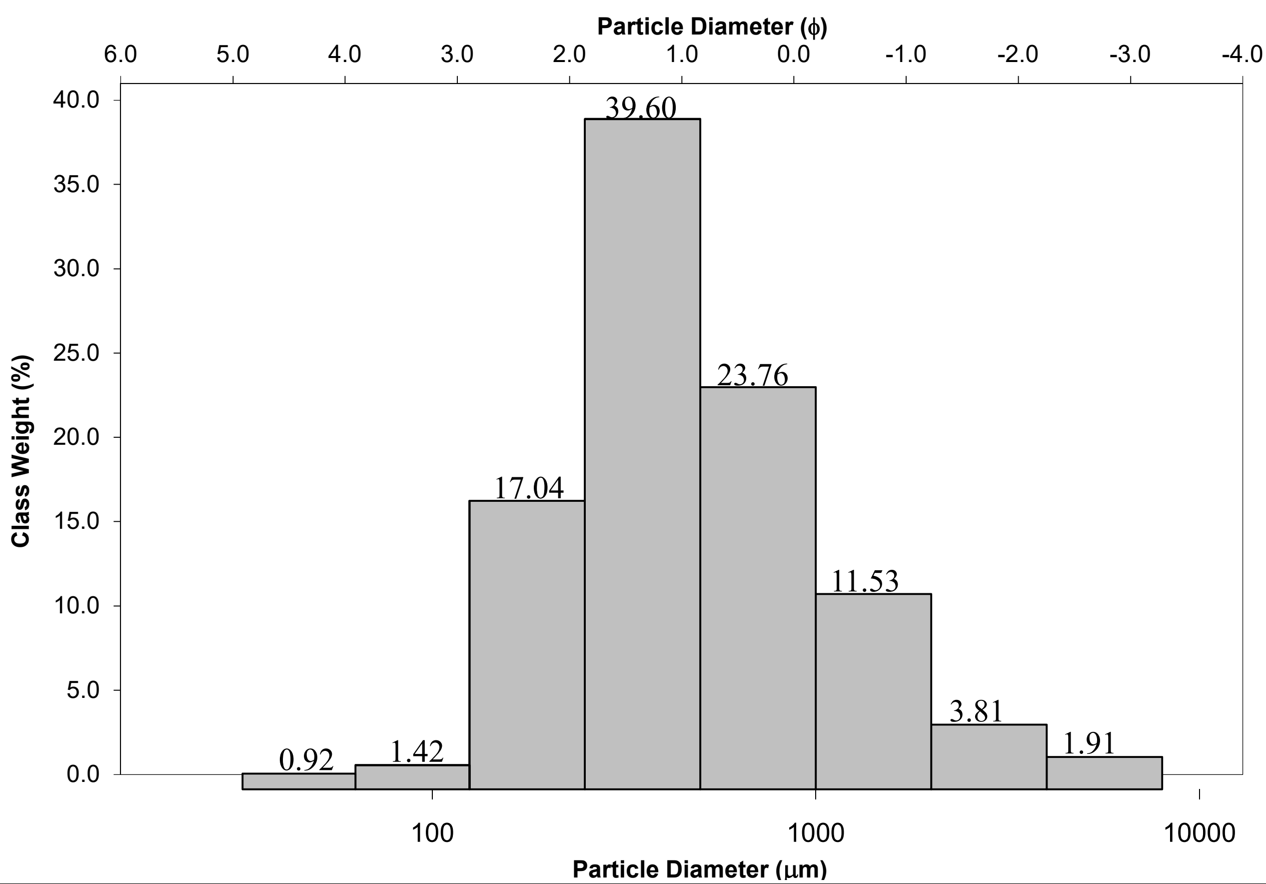
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	170.9	-0.629
MEDIAN or D_{50}:	427.3	1.227
D_{90}:	1546.2	2.549
(D_{90} / D_{10}):	9.047	-4.054
$(D_{90} - D_{10})$:	1375.3	3.178
(D_{75} / D_{25}):	2.891	5.699
$(D_{75} - D_{25})$:	521.8	1.532

GRAIN SIZE DISTRIBUTION

GRAVEL:	5.7%	COARSE SAND:	23.8%
SAND:	93.4%	MEDIUM SAND:	39.6%
MUD:	0.9%	FINE SAND:	17.1%
		V FINE SAND:	1.4%
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:	1.9%	FINE SILT:	0.0%
V FINE GRAVEL:	3.8%	V FINE SILT:	0.0%
V COARSE SAND:	11.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	762.3	477.5	1.066	464.9	1.105	Medium Sand
SORTING (σ):	950.3	2.314	1.211	2.277	1.187	Poorly Sorted
SKEWNESS (Sk):	3.669	0.508	-0.508	0.178	-0.178	Coarse Skewed
KURTOSIS (K):	18.84	3.678	3.678	1.078	1.078	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **312**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

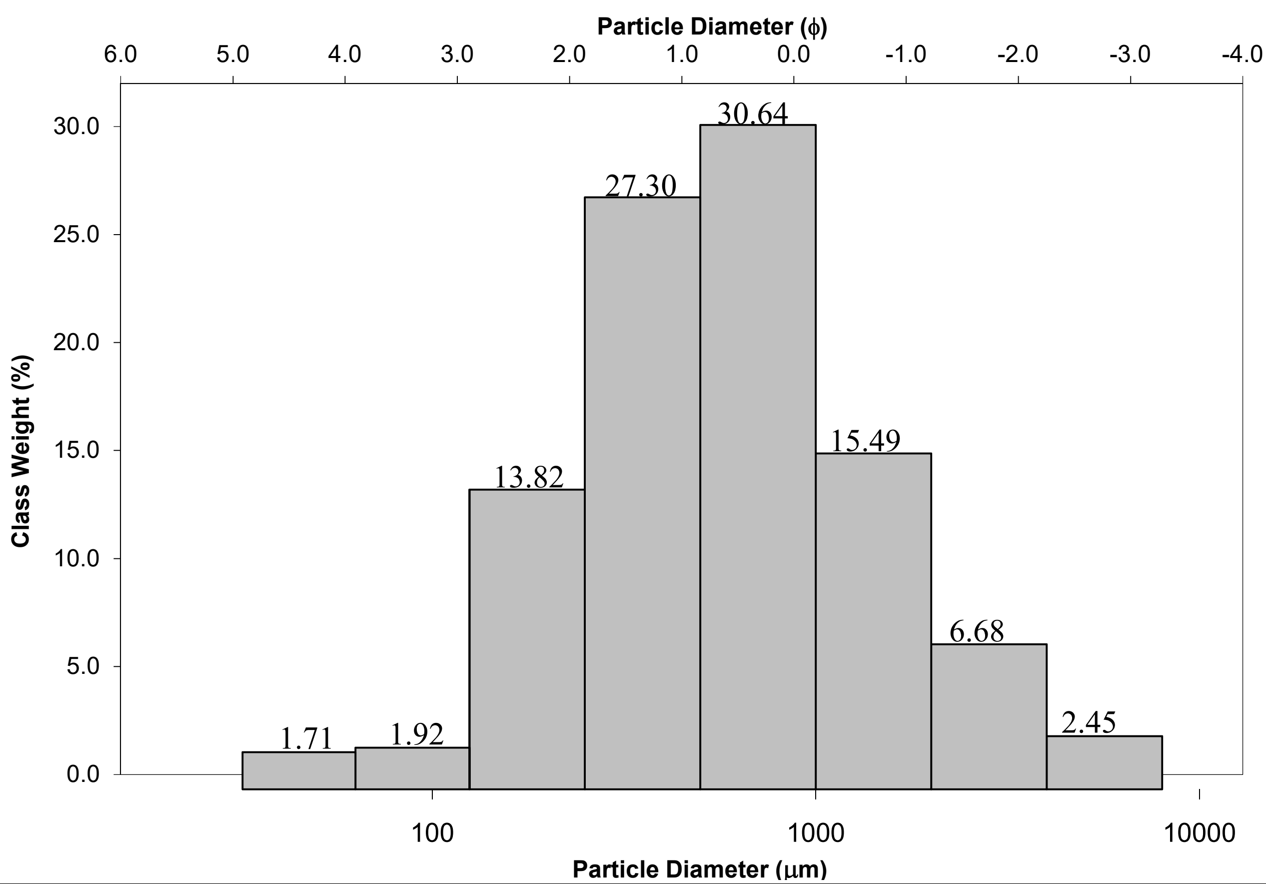
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	172.6	-0.945
MEDIAN or D_{50}:	563.6	0.827
D_{90}:	1924.7	2.535
(D_{90} / D_{10}):	11.15	-2.683
$(D_{90} - D_{10})$:	1752.1	3.479
(D_{75} / D_{25}):	3.271	145.7
$(D_{75} - D_{25})$:	688.6	1.710

GRAIN SIZE DISTRIBUTION

GRAVEL:	9.1%	COARSE SAND:	30.7%
SAND:	89.2%	MEDIUM SAND:	27.3%
MUD:	1.7%	FINE SAND:	13.8%
		V FINE SAND:	1.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.7%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.5%	FINE SILT:	0.0%
V FINE GRAVEL:	6.7%	V FINE SILT:	0.0%
V COARSE SAND:	15.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	941.1	570.2	0.811	578.3	0.790	Coarse Sand
SORTING (σ):	1078.8	2.539	1.344	2.547	1.349	Poorly Sorted
SKEWNESS (Sk):	2.909	0.052	-0.052	0.063	-0.063	Symmetrical
KURTOSIS (K):	12.83	3.216	3.216	1.082	1.082	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **313**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

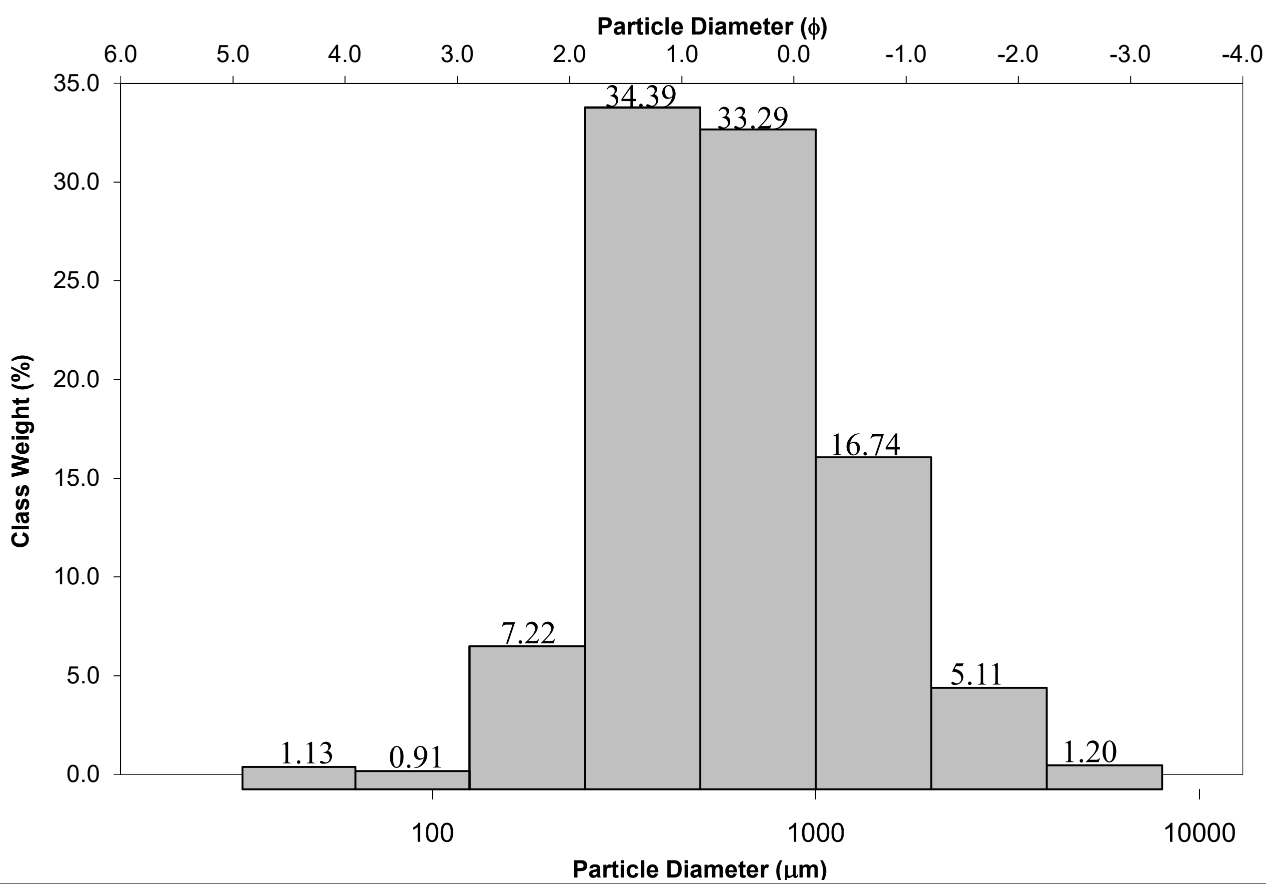
	μm	φ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	253.9	-0.780
MEDIAN or D_{50}:	570.9	0.809
D_{90}:	1717.4	1.978
(D_{90} / D_{10}):	6.764	-2.535
$(D_{90} - D_{10})$:	1463.5	2.758
(D_{75} / D_{25}):	2.796	26.59
$(D_{75} - D_{25})$:	617.1	1.484

GRAIN SIZE DISTRIBUTION

GRAVEL:	6.3%	COARSE SAND:	33.3%
SAND:	92.6%	MEDIUM SAND:	34.4%
MUD:	1.1%	FINE SAND:	7.2%
		V FINE SAND:	0.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.2%	FINE SILT:	0.0%
V FINE GRAVEL:	5.1%	V FINE SILT:	0.0%
V COARSE SAND:	16.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	870.6	593.2	0.753	602.9	0.730	Coarse Sand
SORTING (σ):	866.6	2.207	1.142	2.202	1.139	Poorly Sorted
SKEWNESS (Sk):	3.203	0.035	-0.035	0.091	-0.091	Symmetrical
KURTOSIS (K):	16.77	3.815	3.815	1.062	1.062	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **314**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

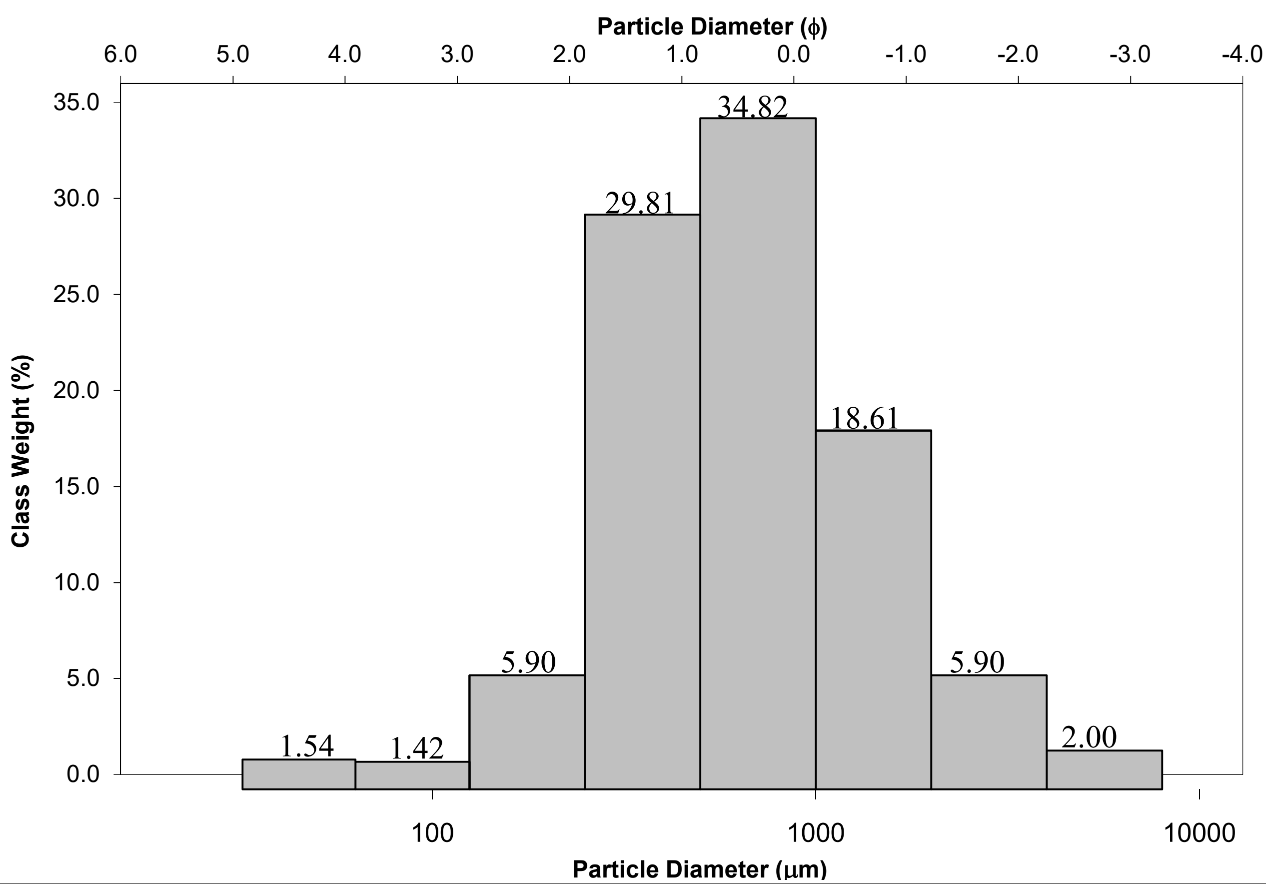
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	257.0	-0.888
MEDIAN or D_{50}:	626.8	0.674
D_{90}:	1850.1	1.960
(D_{90} / D_{10}):	7.199	-2.208
$(D_{90} - D_{10})$:	1593.1	2.848
(D_{75} / D_{25}):	2.906	-17.773
$(D_{75} - D_{25})$:	694.3	1.539

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.9%	COARSE SAND:	34.8%
SAND:	90.6%	MEDIUM SAND:	29.8%
MUD:	1.5%	FINE SAND:	5.9%
		V FINE SAND:	1.4%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.5%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.0%	FINE SILT:	0.0%
V FINE GRAVEL:	5.9%	V FINE SILT:	0.0%
V COARSE SAND:	18.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	962.8	635.6	0.654	649.6	0.622	Coarse Sand
SORTING (σ):	992.1	2.322	1.215	2.310	1.208	Poorly Sorted
SKEWNESS (Sk):	3.046	-0.116	0.116	0.057	-0.057	Symmetrical
KURTOSIS (K):	14.45	3.917	3.917	1.102	1.102	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **315**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

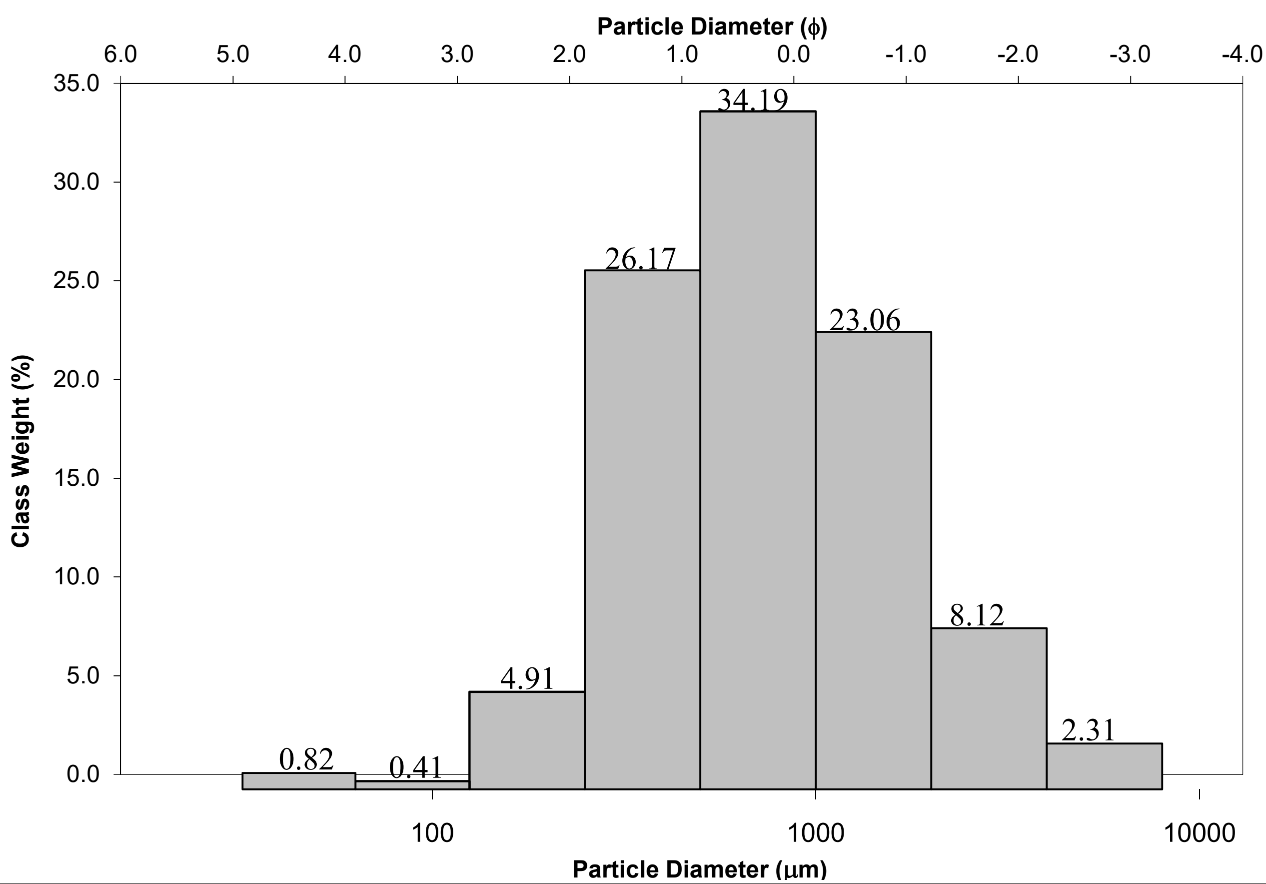
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	277.1	-1.053
MEDIAN or D_{50}:	715.8	0.482
D_{90}:	2075.0	1.852
(D_{90} / D_{10}):	7.489	-1.758
$(D_{90} - D_{10})$:	1797.9	2.905
(D_{75} / D_{25}):	3.132	-3.470
$(D_{75} - D_{25})$:	878.8	1.647

GRAIN SIZE DISTRIBUTION

GRAVEL:	10.4%	COARSE SAND:	34.2%
SAND:	88.8%	MEDIUM SAND:	26.2%
MUD:	0.8%	FINE SAND:	4.9%
		V FINE SAND:	0.4%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.3%	FINE SILT:	0.0%
V FINE GRAVEL:	8.1%	V FINE SILT:	0.0%
V COARSE SAND:	23.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1092.8	736.3	0.442	732.7	0.449	Coarse Sand
SORTING (σ):	1057.1	2.258	1.175	2.275	1.186	Poorly Sorted
SKEWNESS (Sk):	2.662	-0.004	0.004	0.073	-0.073	Symmetrical
KURTOSIS (K):	11.68	3.539	3.539	0.969	0.969	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **409**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

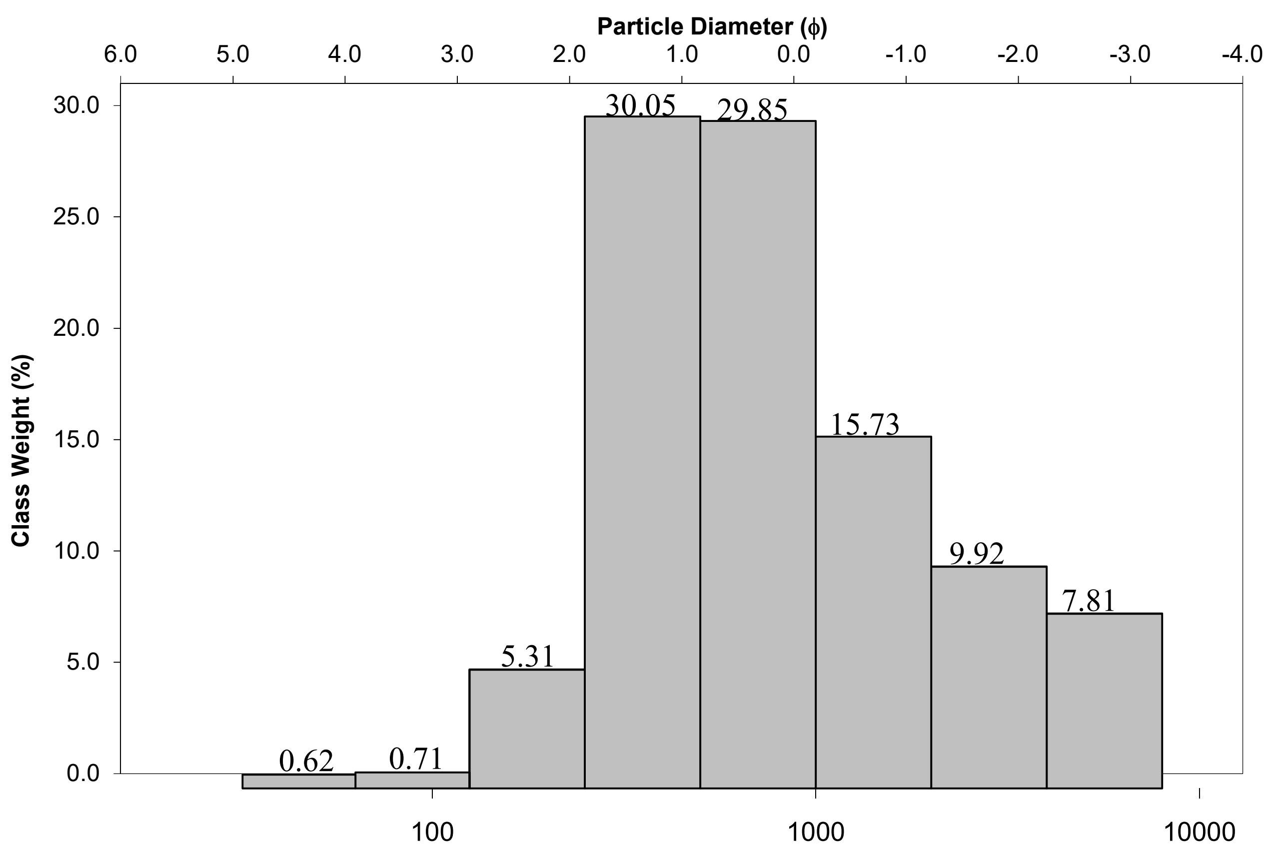
	μm	φ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	270.3	-1.780
MEDIAN or D_{50}:	681.3	0.554
D_{90}:	3433.8	1.887
(D_{90} / D_{10}):	12.70	-1.060
$(D_{90} - D_{10})$:	3163.5	3.667
(D_{75} / D_{25}):	3.801	-2.580
$(D_{75} - D_{25})$:	1070.2	1.927

GRAIN SIZE DISTRIBUTION

GRAVEL:	17.7%	COARSE SAND:	29.9%
SAND:	81.7%	MEDIUM SAND:	30.1%
MUD:	0.6%	FINE SAND:	5.3%
		V FINE SAND:	0.7%
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:	7.8%	FINE SILT:	0.0%
V FINE GRAVEL:	9.9%	V FINE SILT:	0.0%
V COARSE SAND:	15.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1350.1	778.3	0.362	781.6	0.355	Coarse Sand
SORTING (σ):	1565.2	2.606	1.382	2.680	1.422	Poorly Sorted
SKEWNESS (Sk):	2.047	0.369	-0.369	0.229	-0.229	Coarse Skewed
KURTOSIS (K):	6.284	2.890	2.890	0.992	0.992	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **410**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

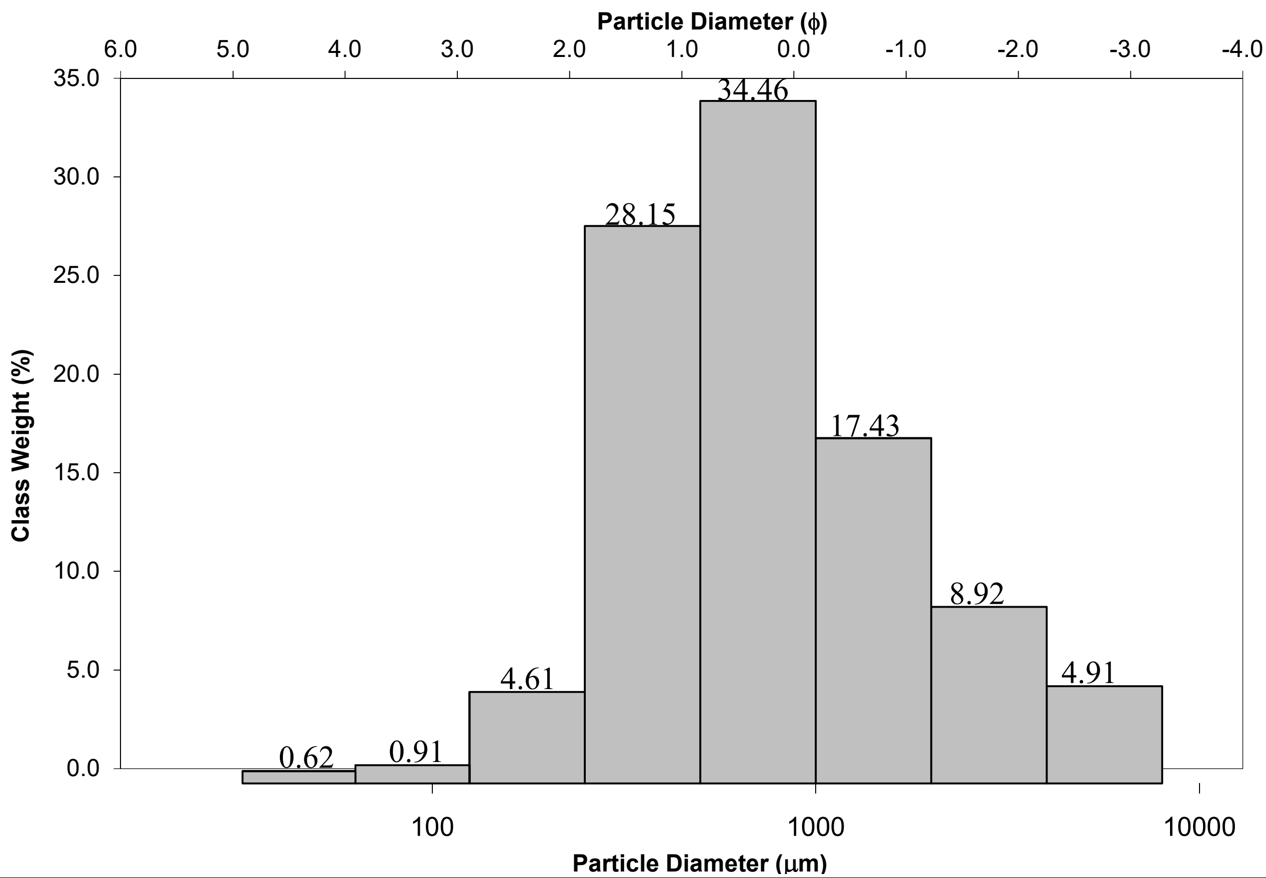
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	275.1	-1.429
MEDIAN or D_{50}:	686.1	0.544
D_{90}:	2693.0	1.862
(D_{90} / D_{10}):	9.789	-1.303
$(D_{90} - D_{10})$:	2417.9	3.291
(D_{75} / D_{25}):	3.223	-3.700
$(D_{75} - D_{25})$:	884.7	1.688

GRAIN SIZE DISTRIBUTION

GRAVEL:	13.8%	COARSE SAND:	34.5%
SAND:	85.6%	MEDIUM SAND:	28.2%
MUD:	0.6%	FINE SAND:	4.6%
		V FINE SAND:	0.9%
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:	4.9%	FINE SILT:	0.0%
V FINE GRAVEL:	8.9%	V FINE SILT:	0.0%
V COARSE SAND:	17.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1197.5	745.0	0.425	737.6	0.439	Coarse Sand
SORTING (σ):	1328.0	2.409	1.269	2.415	1.272	Poorly Sorted
SKEWNESS (Sk):	2.438	0.284	-0.284	0.161	-0.161	Coarse Skewed
KURTOSIS (K):	8.770	3.320	3.320	1.027	1.027	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **411**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

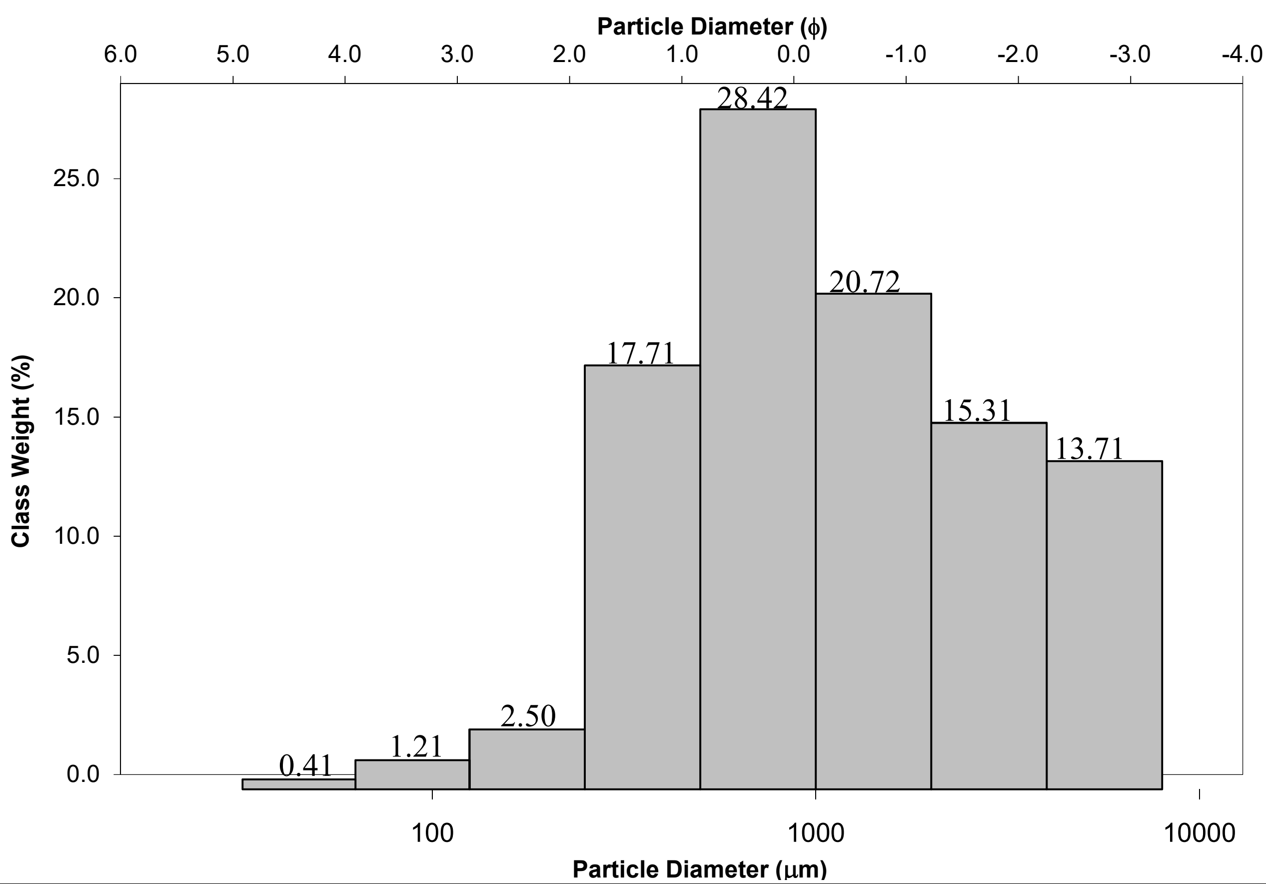
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	314.9	-2.271
MEDIAN or D_{50}:	993.9	0.009
D_{90}:	4825.9	1.667
(D_{90} / D_{10}):	15.33	-0.734
$(D_{90} - D_{10})$:	4511.1	3.938
(D_{75} / D_{25}):	4.442	-0.703
$(D_{75} - D_{25})$:	1859.8	2.151

GRAIN SIZE DISTRIBUTION

GRAVEL:	29.0%	COARSE SAND:	28.4%
SAND:	70.6%	MEDIUM SAND:	17.7%
MUD:	0.4%	FINE SAND:	2.5%
		V FINE SAND:	1.2%
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:	13.7%	FINE SILT:	0.0%
V FINE GRAVEL:	15.3%	V FINE SILT:	0.0%
V COARSE SAND:	20.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1878.8	1106.3	-0.146	1125.9	-0.171	Very Coarse Sand
SORTING (σ):	1854.1	2.721	1.444	2.808	1.489	Poorly Sorted
SKEWNESS (Sk):	1.346	-0.042	0.042	0.162	-0.162	Coarse Skewed
KURTOSIS (K):	3.516	2.586	2.586	0.873	0.873	Platykurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **412**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Fine Gravelly Coarse Sand

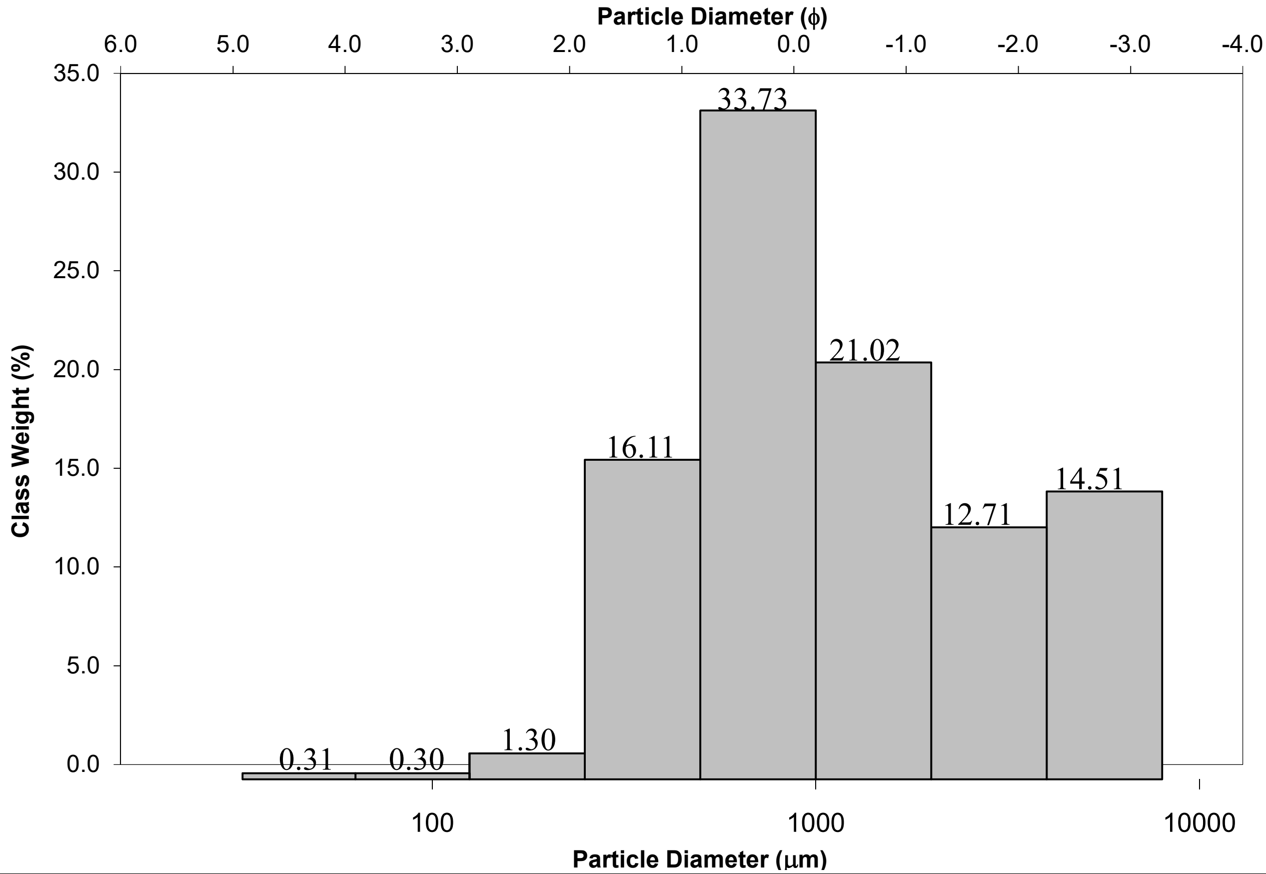
	μm	φ
MODE 1:	750.0	0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	354.2	-2.311
MEDIAN or D_{50}:	964.6	0.052
D_{90}:	4962.4	1.498
(D_{90} / D_{10}):	14.01	-0.648
$(D_{90} - D_{10})$:	4608.2	3.809
(D_{75} / D_{25}):	3.913	-0.675
$(D_{75} - D_{25})$:	1681.1	1.968

GRAIN SIZE DISTRIBUTION

GRAVEL:	27.2%	COARSE SAND:	33.7%
SAND:	72.5%	MEDIUM SAND:	16.1%
MUD:	0.3%	FINE SAND:	1.3%
		V FINE SAND:	0.3%
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:	14.5%	FINE SILT:	0.0%
V FINE GRAVEL:	12.7%	V FINE SILT:	0.0%
V COARSE SAND:	21.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1883.9	1142.2	-0.192	1177.2	-0.235	Very Coarse Sand
SORTING (σ):	1872.5	2.557	1.354	2.691	1.428	Poorly Sorted
SKEWNESS (Sk):	1.392	0.191	-0.191	0.250	-0.250	Coarse Skewed
KURTOSIS (K):	3.533	2.544	2.544	0.929	0.929	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **413**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

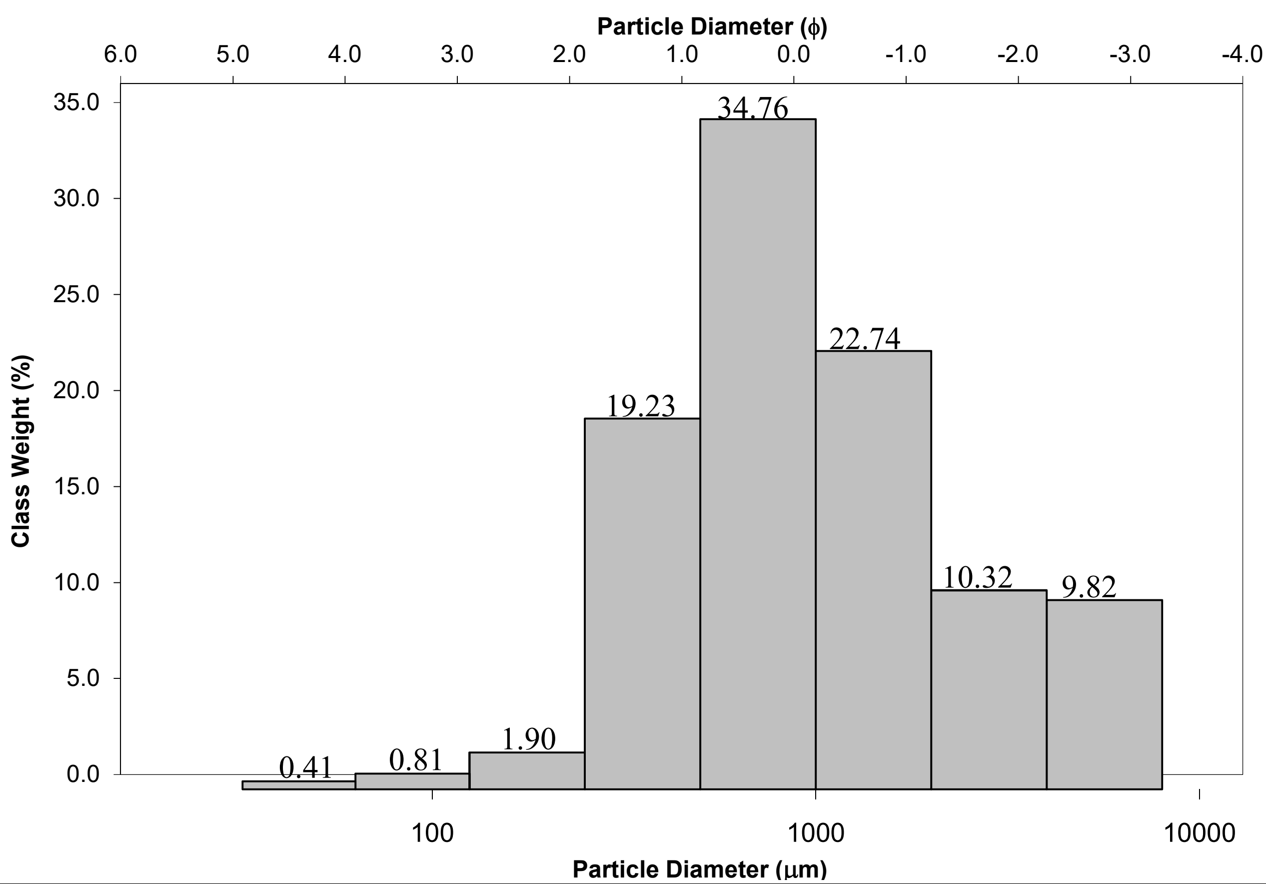
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	320.5	-1.983
MEDIAN or D_{50}:	867.8	0.205
D_{90}:	3951.8	1.642
(D_{90} / D_{10}):	12.33	-0.828
$(D_{90} - D_{10})$:	3631.4	3.624
(D_{75} / D_{25}):	3.272	-1.175
$(D_{75} - D_{25})$:	1197.5	1.710

GRAIN SIZE DISTRIBUTION

GRAVEL:	20.1%	COARSE SAND:	34.8%
SAND:	79.5%	MEDIUM SAND:	19.2%
MUD:	0.4%	FINE SAND:	1.9%
		V FINE SAND:	0.8%
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:	9.8%	FINE SILT:	0.0%
V FINE GRAVEL:	10.3%	V FINE SILT:	0.0%
V COARSE SAND:	22.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1577.4	971.3	0.042	969.7	0.044	Coarse Sand
SORTING (σ):	1646.5	2.481	1.311	2.546	1.348	Poorly Sorted
SKEWNESS (Sk):	1.830	0.193	-0.193	0.202	-0.202	Coarse Skewed
KURTOSIS (K):	5.264	3.040	3.040	1.053	1.053	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **414**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

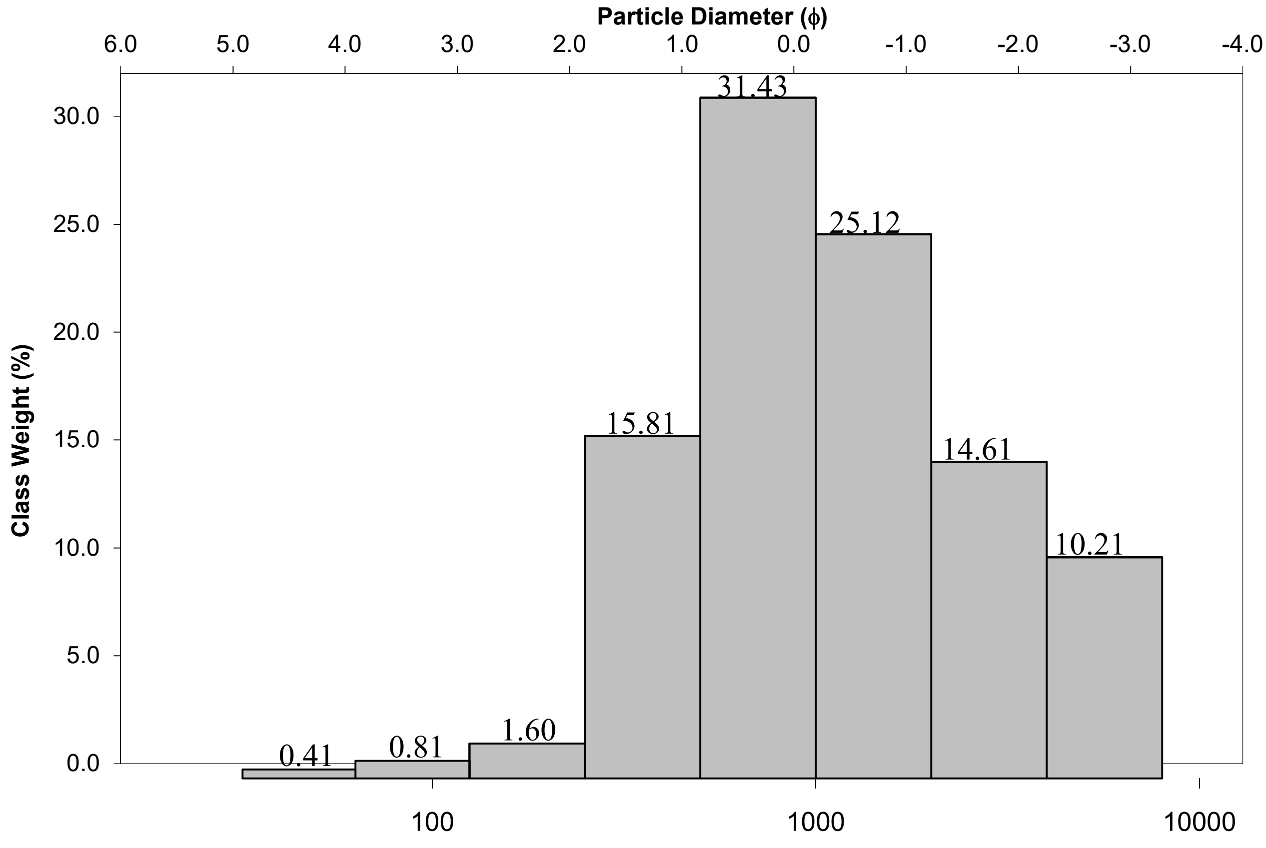
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	342.7	-2.021
MEDIAN or D_{50}:	998.9	0.002
D_{90}:	4057.5	1.545
(D_{90} / D_{10}):	11.84	-0.765
$(D_{90} - D_{10})$:	3714.8	3.566
(D_{75} / D_{25}):	3.458	-0.803
$(D_{75} - D_{25})$:	1414.8	1.790

GRAIN SIZE DISTRIBUTION

GRAVEL:	24.8%	COARSE SAND:	31.4%
SAND:	74.8%	MEDIUM SAND:	15.8%
MUD:	0.4%	FINE SAND:	1.6%
		V FINE SAND:	0.8%
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:	10.2%	FINE SILT:	0.0%
V FINE GRAVEL:	14.6%	V FINE SILT:	0.0%
V COARSE SAND:	25.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1726.9	1086.6	-0.120	1106.2	-0.146	Very Coarse Sand
SORTING (σ):	1665.5	2.487	1.315	2.557	1.355	Poorly Sorted
SKEWNESS (Sk):	1.617	-0.012	0.012	0.154	-0.154	Coarse Skewed
KURTOSIS (K):	4.604	2.966	2.966	1.001	1.001	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **415**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Fine Gravel

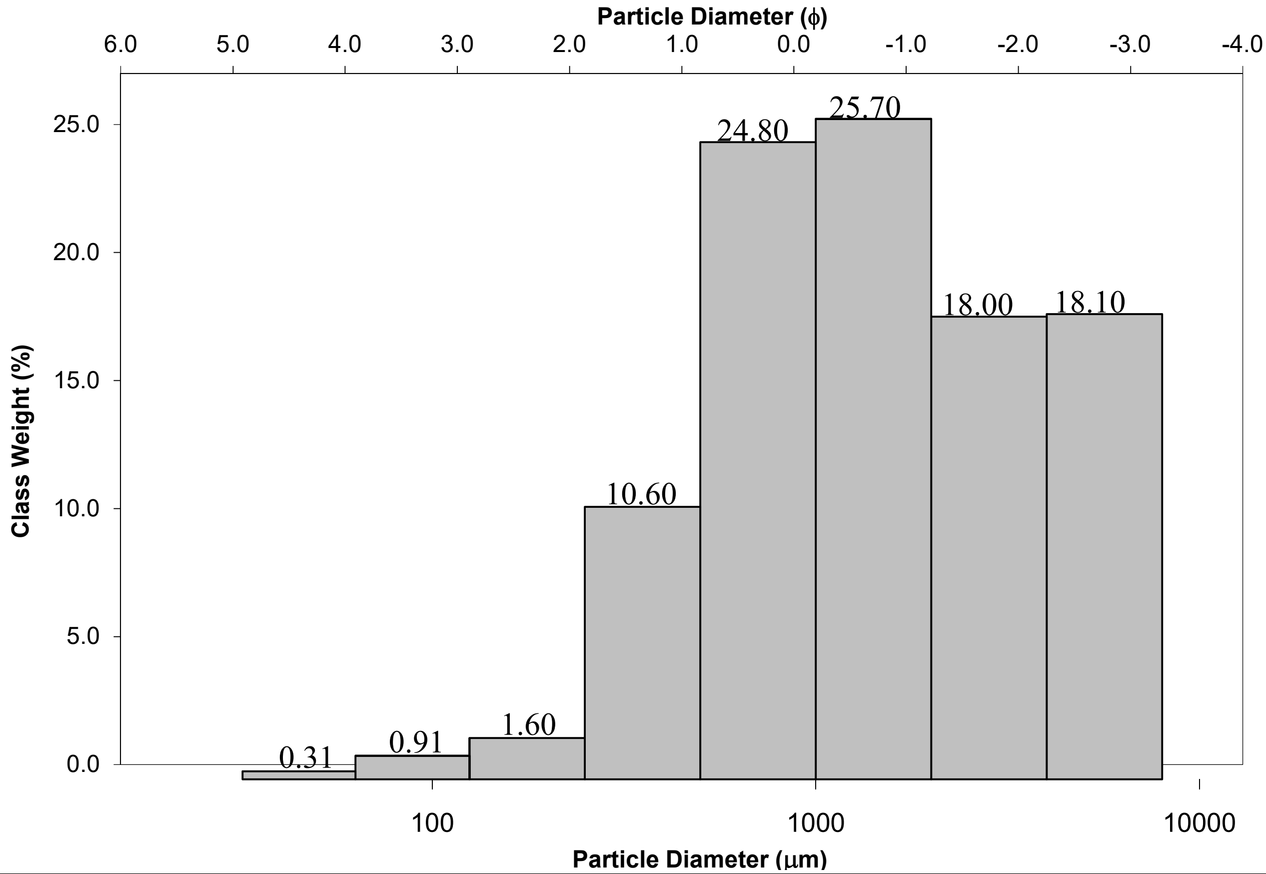
	μm	ϕ
MODE 1:	1500.0	-0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	400.3	-2.448
MEDIAN or D_{50}:	1374.7	-0.459
D_{90}:	5454.8	1.321
(D_{90} / D_{10}):	13.63	-0.540
$(D_{90} - D_{10})$:	5054.4	3.768
(D_{75} / D_{25}):	4.435	-0.329
$(D_{75} - D_{25})$:	2375.2	2.149

GRAIN SIZE DISTRIBUTION

GRAVEL:	36.1%	COARSE SAND:	24.8%
SAND:	63.6%	MEDIUM SAND:	10.6%
MUD:	0.3%	FINE SAND:	1.6%
		V FINE SAND:	0.9%
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:	18.1%	FINE SILT:	0.0%
V FINE GRAVEL:	18.0%	V FINE SILT:	0.0%
V COARSE SAND:	25.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	2241.2	1397.8	-0.483	1474.3	-0.560	Very Coarse Sand
SORTING (σ):	1961.2	2.624	1.392	2.708	1.437	Poorly Sorted
SKEWNESS (Sk):	1.036	-0.276	0.276	0.052	-0.052	Symmetrical
KURTOSIS (K):	2.658	2.769	2.769	0.861	0.861	Platykurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **416**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

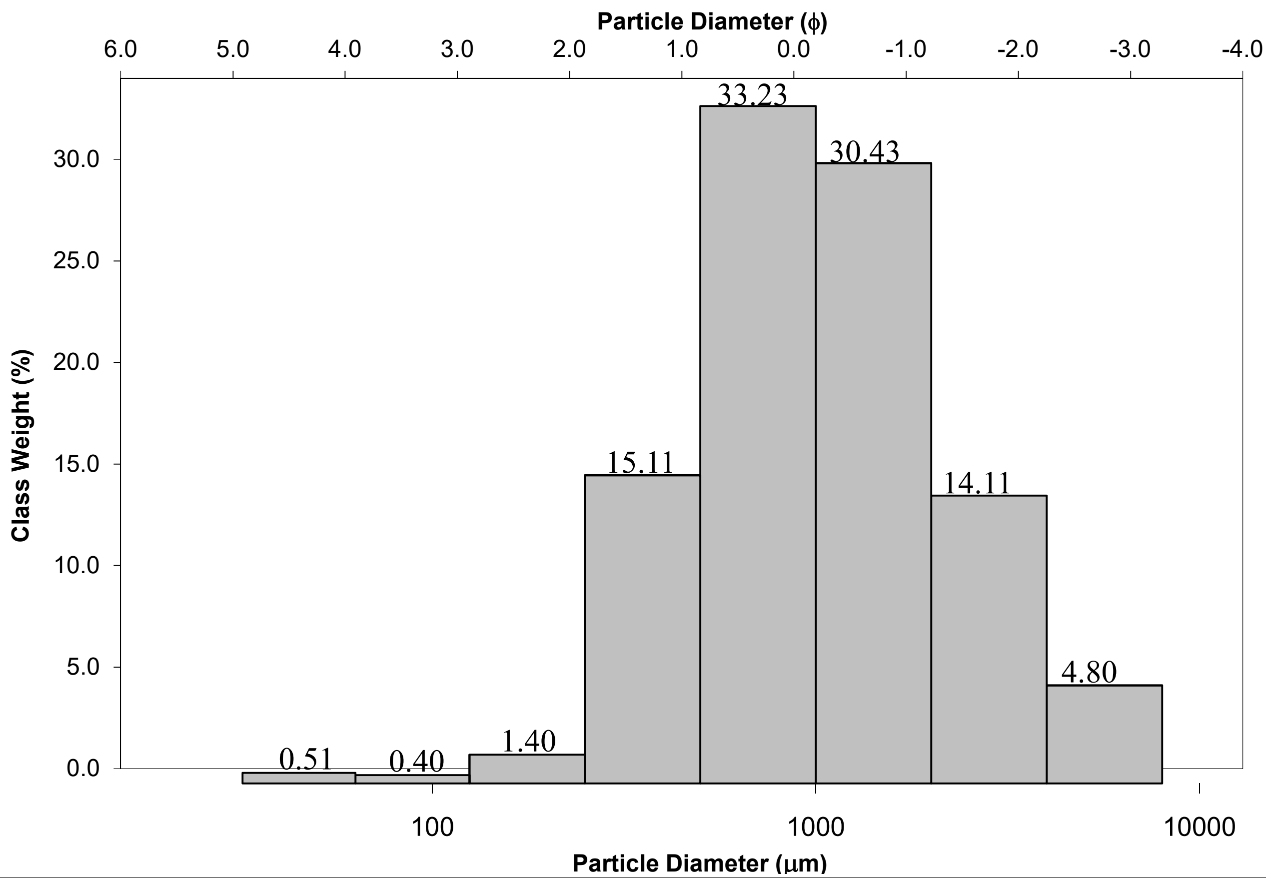
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	355.8	-1.632
MEDIAN or D_{50}:	986.5	0.020
D_{90}:	3099.2	1.491
(D_{90} / D_{10}):	8.710	-0.913
$(D_{90} - D_{10})$:	2743.4	3.123
(D_{75} / D_{25}):	2.973	-0.965
$(D_{75} - D_{25})$:	1155.6	1.572

GRAIN SIZE DISTRIBUTION

GRAVEL:	18.9%	COARSE SAND:	33.2%
SAND:	80.6%	MEDIUM SAND:	15.1%
MUD:	0.5%	FINE SAND:	1.4%
		V FINE SAND:	0.4%
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:	4.8%	FINE SILT:	0.0%
V FINE GRAVEL:	14.1%	V FINE SILT:	0.0%
V COARSE SAND:	30.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1477.3	1013.7	-0.020	1021.8	-0.031	Very Coarse Sand
SORTING (σ):	1308.0	2.240	1.163	2.222	1.152	Poorly Sorted
SKEWNESS (Sk):	2.037	-0.130	0.130	0.060	-0.060	Symmetrical
KURTOSIS (K):	7.260	3.583	3.583	0.993	0.993	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **509**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Medium Sand

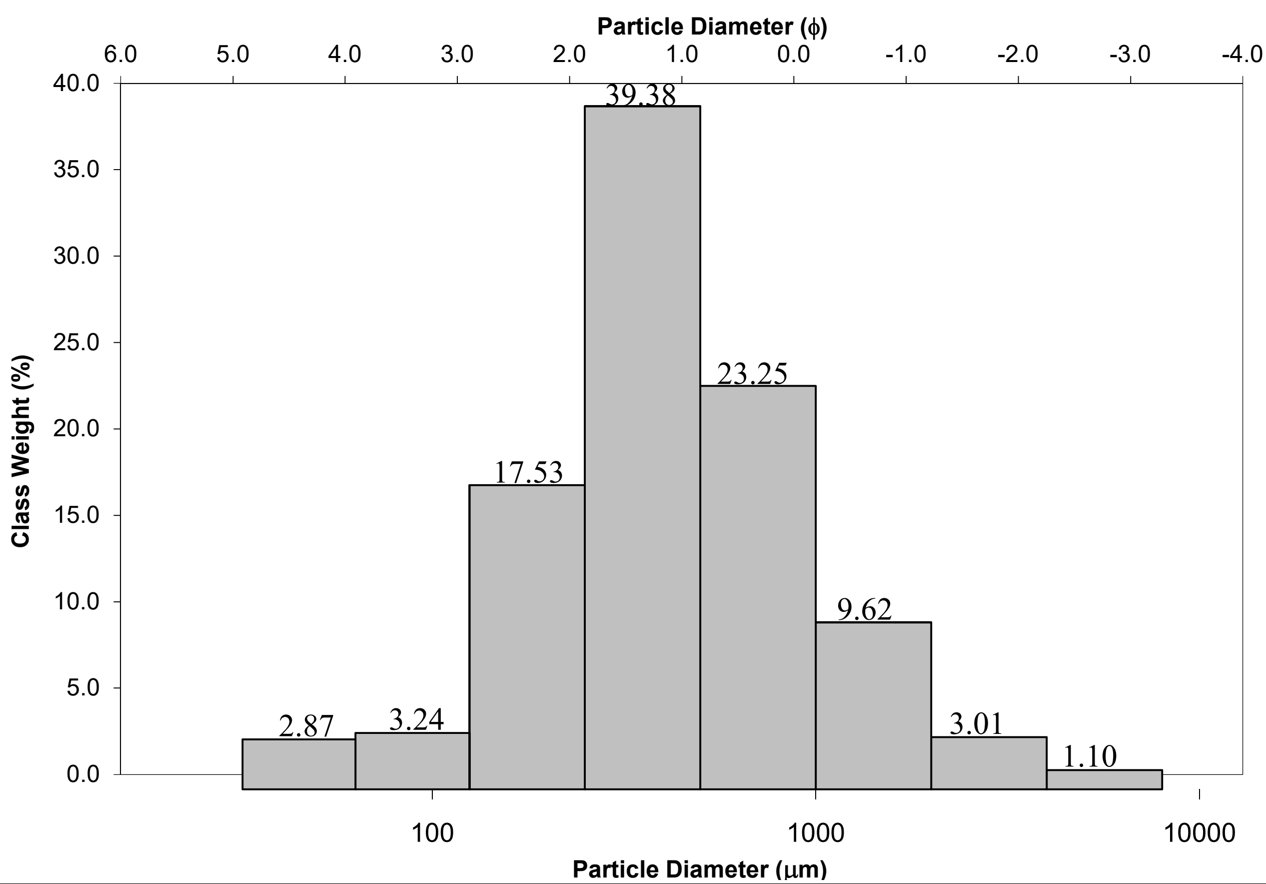
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	146.3	-0.389
MEDIAN or D_{50}:	397.9	1.330
D_{90}:	1309.1	2.773
(D_{90} / D_{10}):	8.949	-7.137
(D_{90} - D_{10}):	1162.8	3.162
(D_{75} / D_{25}):	2.789	4.059
(D_{75} - D_{25}):	458.7	1.480

GRAIN SIZE DISTRIBUTION

GRAVEL:	4.1%	COARSE SAND:	23.3%
SAND:	93.1%	MEDIUM SAND:	39.4%
MUD:	2.8%	FINE SAND:	17.6%
		V FINE SAND:	3.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.1%	FINE SILT:	0.0%
V FINE GRAVEL:	3.0%	V FINE SILT:	0.0%
V COARSE SAND:	9.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	660.5	416.5	1.263	410.1	1.286	Medium Sand
SORTING (σ):	800.8	2.378	1.250	2.335	1.223	Poorly Sorted
SKEWNESS (Sk):	4.055	0.117	-0.117	0.058	-0.058	Symmetrical
KURTOSIS (K):	24.16	3.766	3.766	1.169	1.169	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **510**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

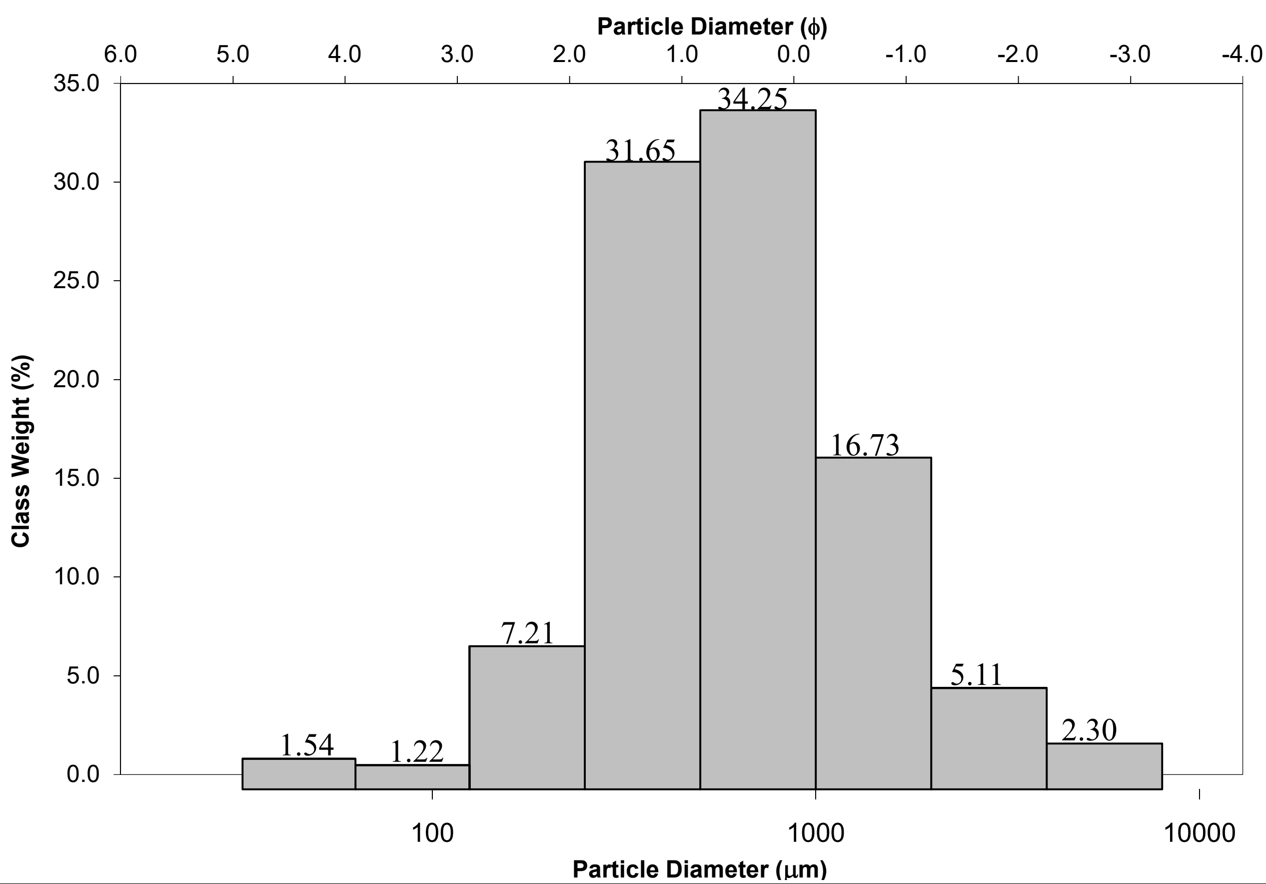
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	250.4	-0.846
MEDIAN or D_{50}:	592.8	0.754
D_{90}:	1796.9	1.997
(D_{90} / D_{10}):	7.175	-2.362
$(D_{90} - D_{10})$:	1546.5	2.843
(D_{75} / D_{25}):	2.826	61.31
$(D_{75} - D_{25})$:	635.1	1.499

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.4%	COARSE SAND:	34.3%
SAND:	91.1%	MEDIUM SAND:	31.7%
MUD:	1.5%	FINE SAND:	7.2%
		V FINE SAND:	1.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.5%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.3%	FINE SILT:	0.0%
V FINE GRAVEL:	5.1%	V FINE SILT:	0.0%
V COARSE SAND:	16.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	933.7	607.9	0.718	619.1	0.692	Coarse Sand
SORTING (σ):	1017.0	2.325	1.218	2.302	1.203	Poorly Sorted
SKEWNESS (Sk):	3.207	0.009	-0.009	0.077	-0.077	Symmetrical
KURTOSIS (K):	15.15	3.931	3.931	1.136	1.136	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **511** ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

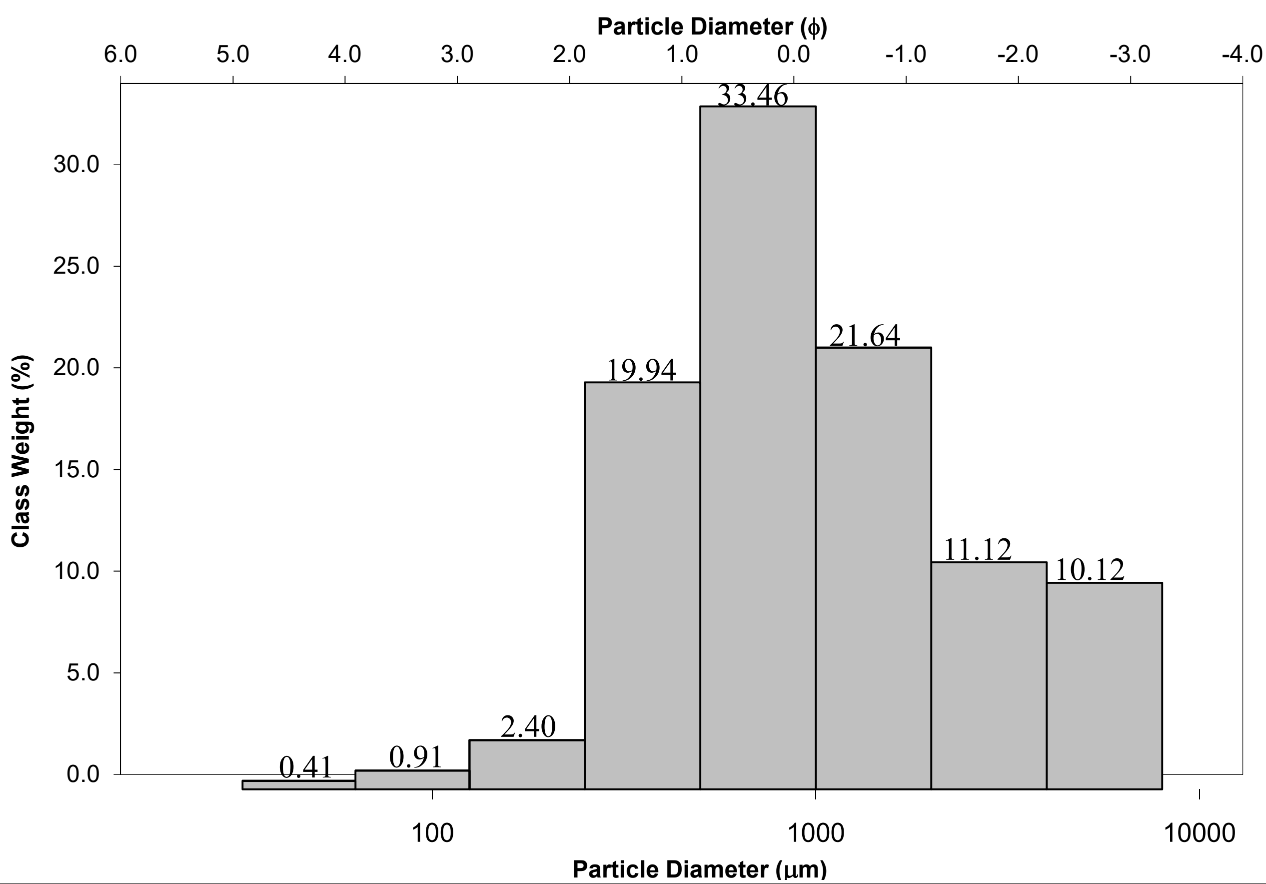
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	311.1	-2.012
MEDIAN or D_{50}:	863.0	0.213
D_{90}:	4033.1	1.684
(D_{90} / D_{10}):	12.96	-0.837
$(D_{90} - D_{10})$:	3722.0	3.696
(D_{75} / D_{25}):	3.449	-1.161
$(D_{75} - D_{25})$:	1259.0	1.786

GRAIN SIZE DISTRIBUTION

GRAVEL:	21.2%	COARSE SAND:	33.5%
SAND:	78.4%	MEDIUM SAND:	19.9%
MUD:	0.4%	FINE SAND:	2.4%
		V FINE SAND:	0.9%
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:	10.1%	FINE SILT:	0.0%
V FINE GRAVEL:	11.1%	V FINE SILT:	0.0%
V COARSE SAND:	21.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1596.9	967.3	0.048	971.6	0.042	Coarse Sand
SORTING (σ):	1672.9	2.539	1.344	2.615	1.387	Poorly Sorted
SKEWNESS (Sk):	1.766	0.168	-0.168	0.202	-0.202	Coarse Skewed
KURTOSIS (K):	5.012	2.910	2.910	1.019	1.019	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **513**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Fine Gravel

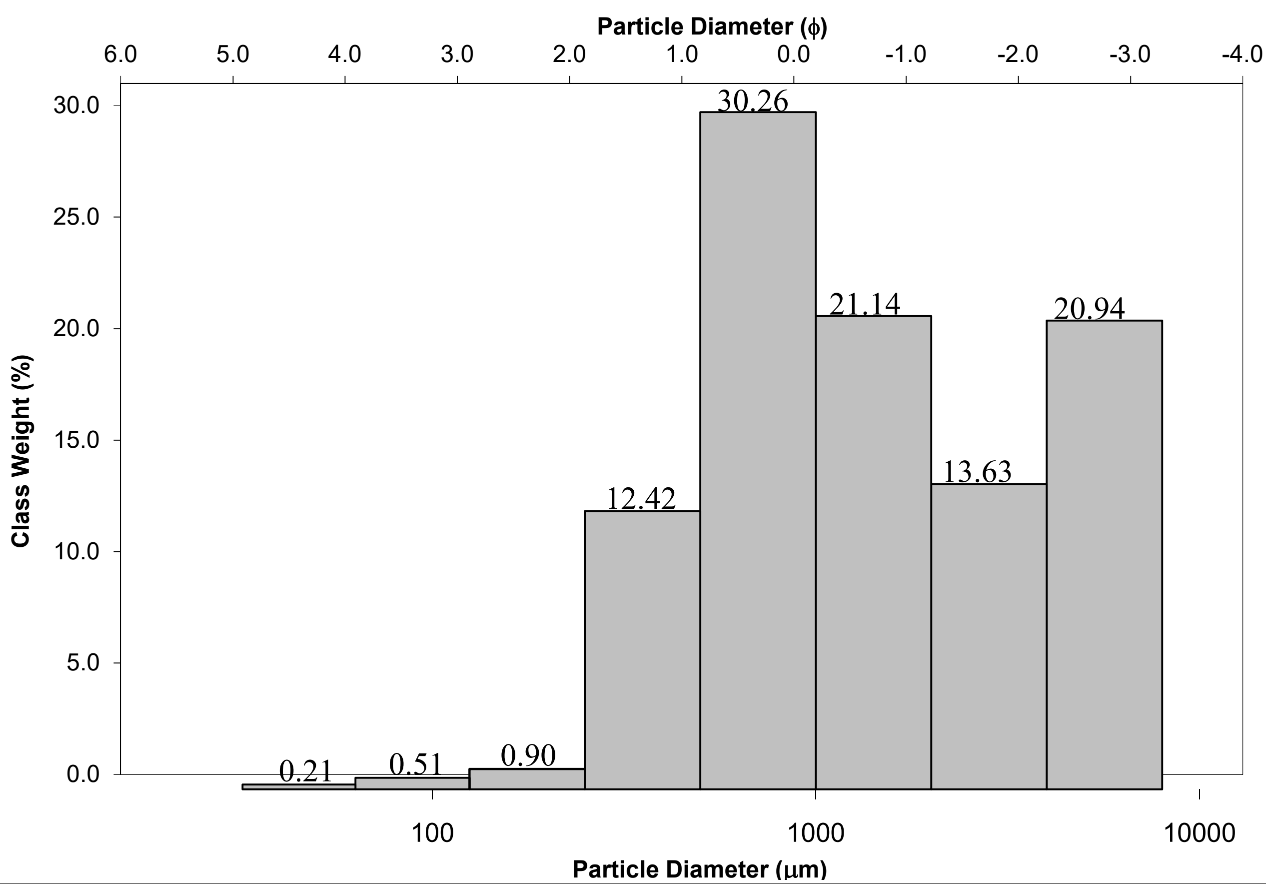
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	399.4	-2.522
MEDIAN or D_{50}:	1205.9	-0.270
D_{90}:	5745.7	1.324
(D_{90} / D_{10}):	14.39	-0.525
$(D_{90} - D_{10})$:	5346.3	3.847
(D_{75} / D_{25}):	5.062	-0.374
$(D_{75} - D_{25})$:	2611.1	2.340

GRAIN SIZE DISTRIBUTION

GRAVEL:	34.6%	COARSE SAND:	30.3%
SAND:	65.2%	MEDIUM SAND:	12.4%
MUD:	0.2%	FINE SAND:	0.9%
		V FINE SAND:	0.5%
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:	20.9%	FINE SILT:	0.0%
V FINE GRAVEL:	13.6%	V FINE SILT:	0.0%
V COARSE SAND:	21.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	2258.3	1363.2	-0.447	1437.7	-0.524	Very Coarse Sand
SORTING (σ):	2080.7	2.653	1.408	2.775	1.473	Poorly Sorted
SKEWNESS (Sk):	0.989	0.007	-0.007	0.175	-0.175	Coarse Skewed
KURTOSIS (K):	2.380	2.288	2.288	0.786	0.786	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **514**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

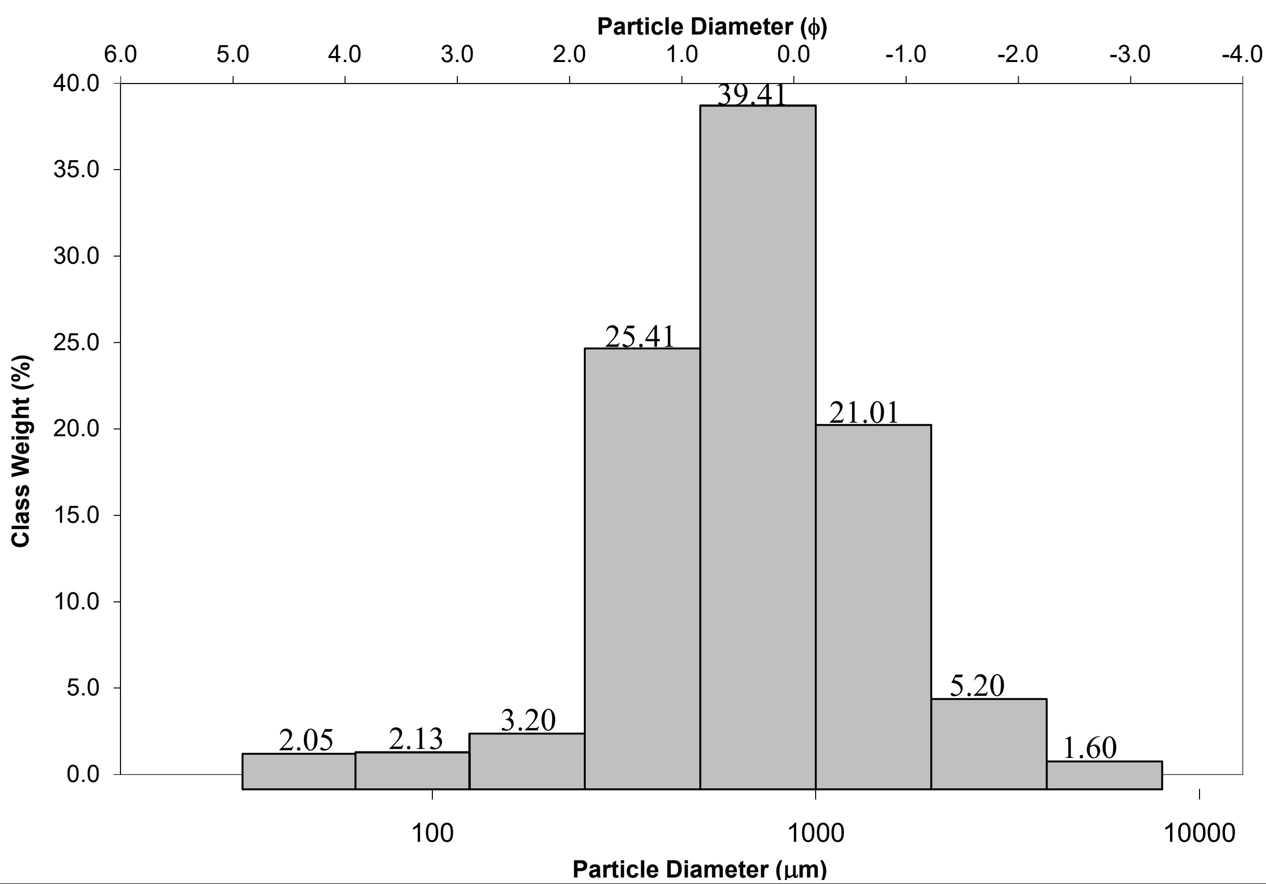
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	269.0	-0.848
MEDIAN or D_{50}:	677.3	0.562
D_{90}:	1800.1	1.894
(D_{90} / D_{10}):	6.691	-2.233
$(D_{90} - D_{10})$:	1531.1	2.742
(D_{75} / D_{25}):	2.711	-9.694
$(D_{75} - D_{25})$:	692.8	1.439

GRAIN SIZE DISTRIBUTION

GRAVEL:	6.8%	COARSE SAND:	39.4%
SAND:	91.2%	MEDIUM SAND:	25.4%
MUD:	2.0%	FINE SAND:	3.2%
		V FINE SAND:	2.1%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.6%	FINE SILT:	0.0%
V FINE GRAVEL:	5.2%	V FINE SILT:	0.0%
V COARSE SAND:	21.0%	CLAY:	0.0%

	METHOD OF MOMENTS Arithmetic μm	Geometric μm	Logarithmic φ	FOLK & WARD METHOD Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	967.6	660.4	0.599	681.8	0.553	Coarse Sand
SORTING (σ):	916.9	2.298	1.200	2.252	1.171	Poorly Sorted
SKEWNESS (Sk):	3.124	-0.491	0.491	-0.024	0.024	Symmetrical
KURTOSIS (K):	15.92	4.525	4.525	1.159	1.159	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **515**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

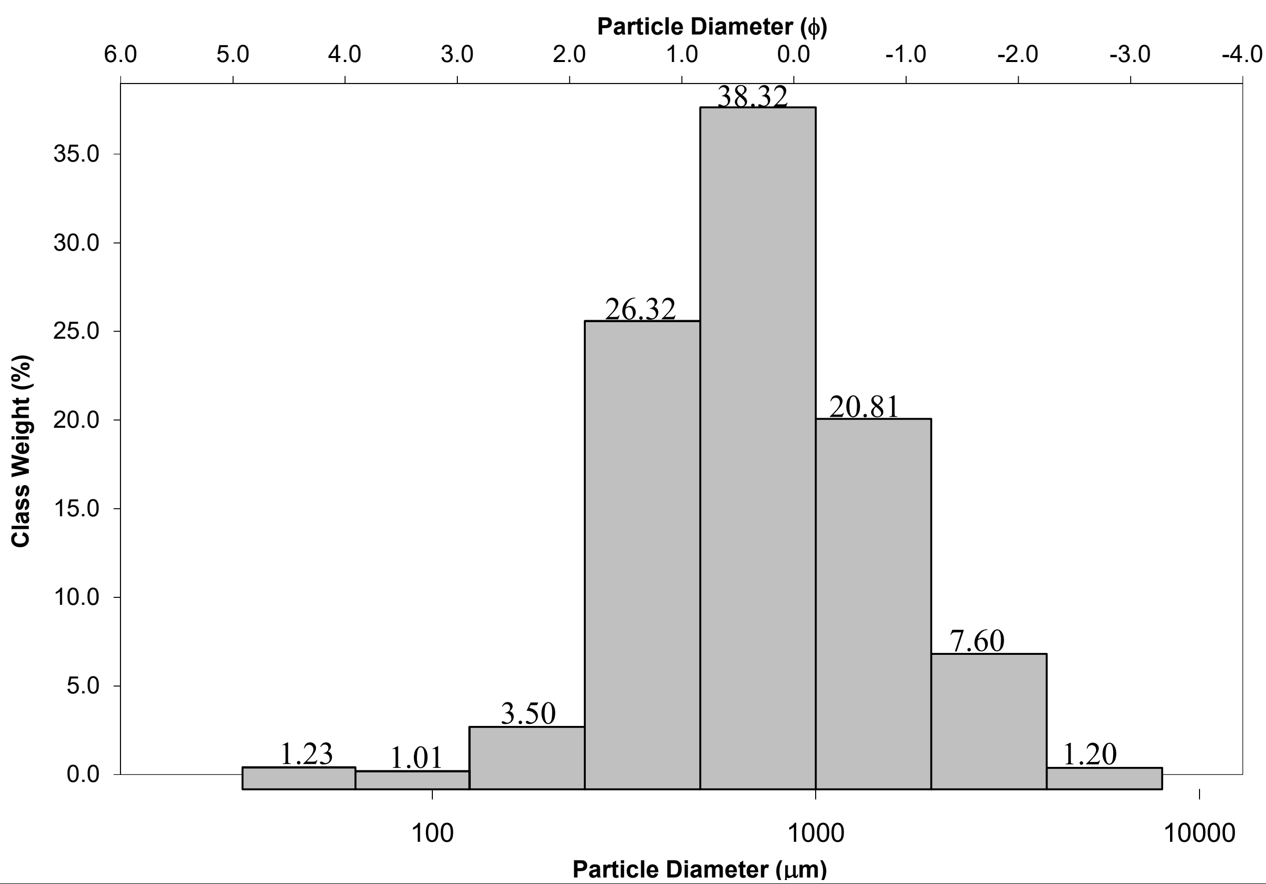
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	279.9	-0.943
MEDIAN or D_{50}:	691.9	0.531
D_{90}:	1922.2	1.837
(D_{90} / D_{10}):	6.867	-1.948
$(D_{90} - D_{10})$:	1642.3	2.780
(D_{75} / D_{25}):	2.808	-5.699
$(D_{75} - D_{25})$:	751.1	1.489

GRAIN SIZE DISTRIBUTION

GRAVEL:	8.8%	COARSE SAND:	38.3%
SAND:	90.0%	MEDIUM SAND:	26.3%
MUD:	1.2%	FINE SAND:	3.5%
		V FINE SAND:	1.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.2%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.2%	FINE SILT:	0.0%
V FINE GRAVEL:	7.6%	V FINE SILT:	0.0%
V COARSE SAND:	20.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1007.0	699.9	0.515	709.4	0.495	Coarse Sand
SORTING (σ):	908.7	2.206	1.142	2.184	1.127	Poorly Sorted
SKEWNESS (Sk):	2.682	-0.248	0.248	0.073	-0.073	Symmetrical
KURTOSIS (K):	12.84	4.125	4.125	1.019	1.019	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **516**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

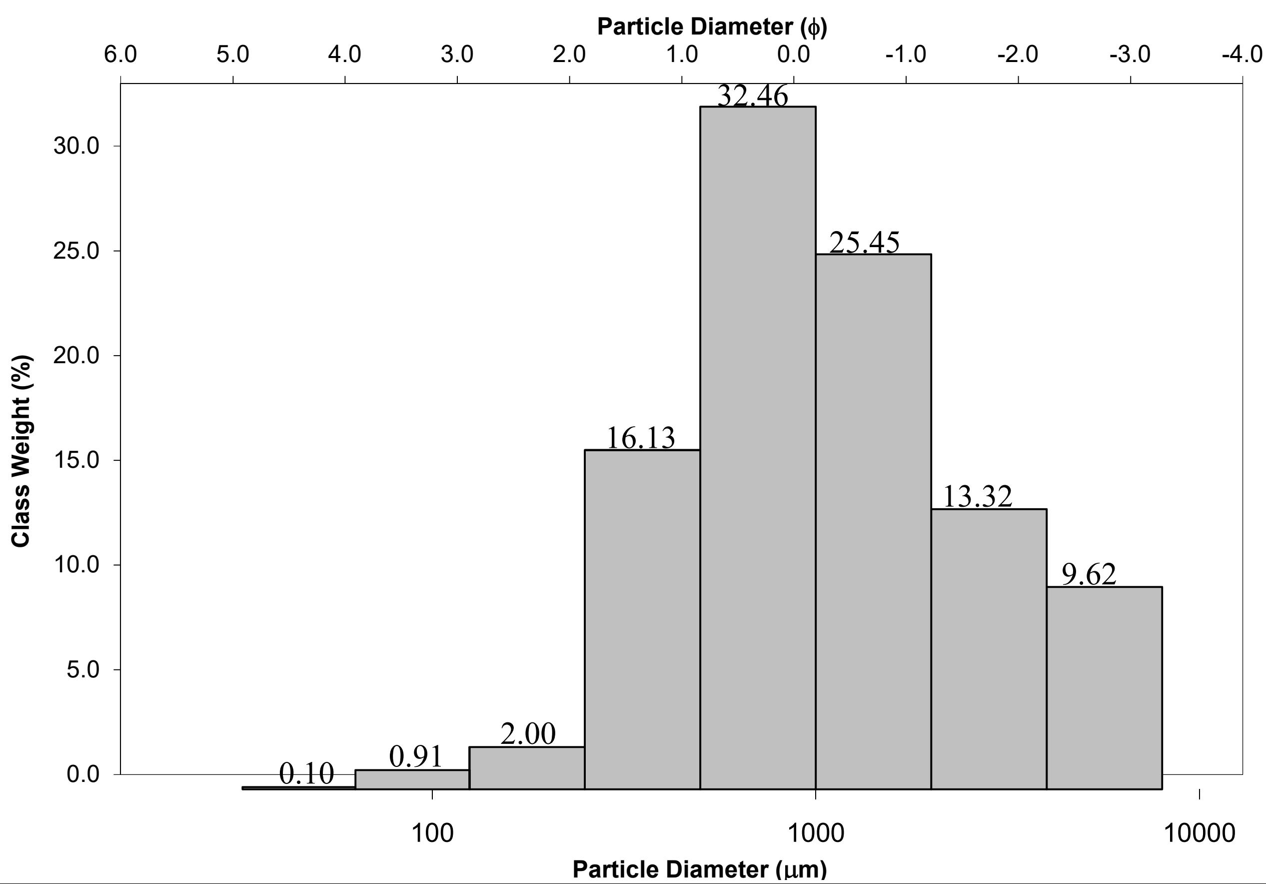
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	337.6	-1.971
MEDIAN or D_{50}:	966.3	0.049
D_{90}:	3921.6	1.566
(D_{90} / D_{10}):	11.61	-0.795
$(D_{90} - D_{10})$:	3583.9	3.538
(D_{75} / D_{25}):	3.337	-0.891
$(D_{75} - D_{25})$:	1324.5	1.739

GRAIN SIZE DISTRIBUTION

GRAVEL:	22.9%	COARSE SAND:	32.5%
SAND:	77.0%	MEDIUM SAND:	16.1%
MUD:	0.1%	FINE SAND:	2.0%
		V FINE SAND:	0.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	9.6%	FINE SILT:	0.0%
V FINE GRAVEL:	13.3%	V FINE SILT:	0.0%
V COARSE SAND:	25.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1667.4	1055.0	-0.077	1066.2	-0.092	Very Coarse Sand
SORTING (σ):	1631.3	2.441	1.288	2.530	1.339	Poorly Sorted
SKEWNESS (Sk):	1.713	0.106	-0.106	0.159	-0.159	Coarse Skewed
KURTOSIS (K):	4.965	2.795	2.795	1.027	1.027	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **517**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

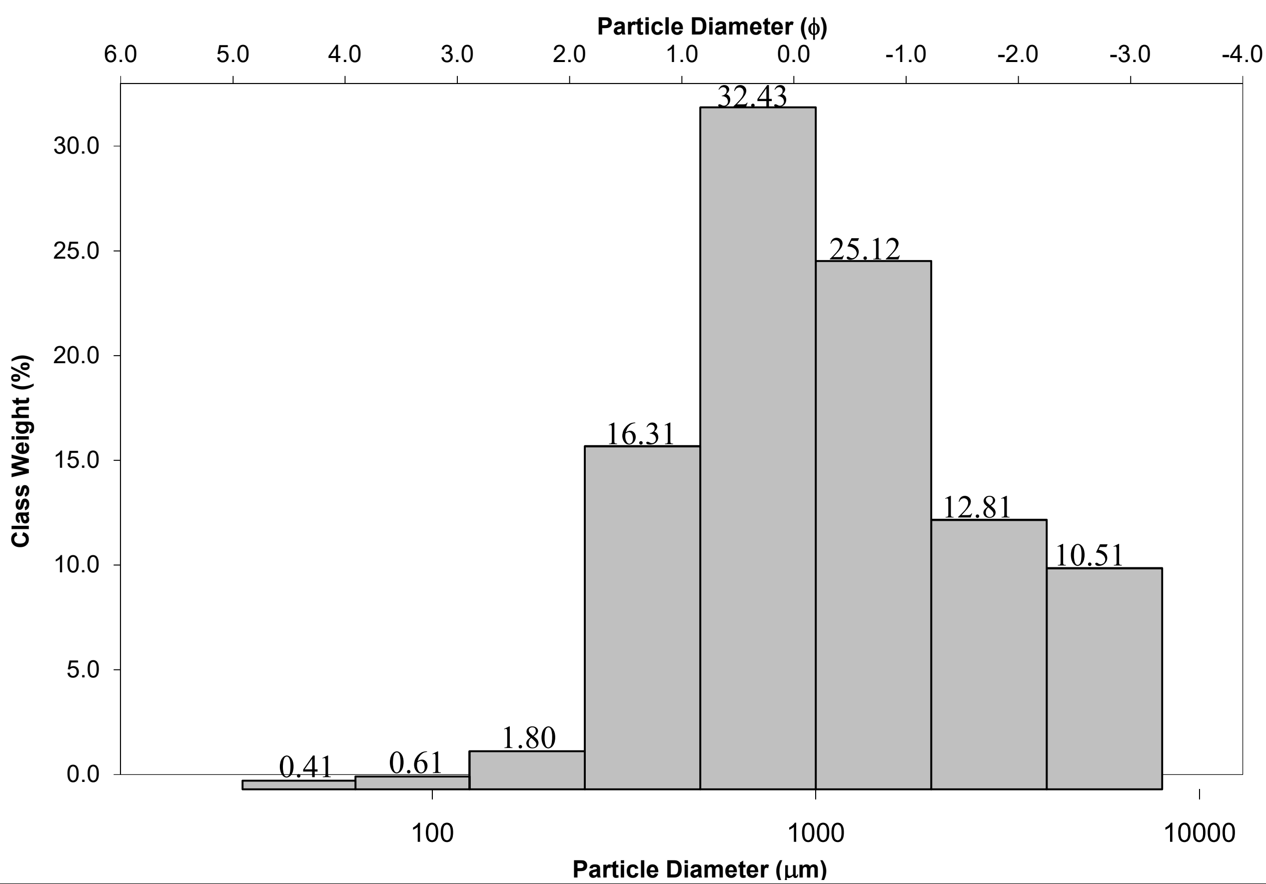
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	339.4	-2.049
MEDIAN or D_{50}:	967.4	0.048
D_{90}:	4137.0	1.559
(D_{90} / D_{10}):	12.19	-0.761
$(D_{90} - D_{10})$:	3797.6	3.607
(D_{75} / D_{25}):	3.368	-0.877
$(D_{75} - D_{25})$:	1342.6	1.752

GRAIN SIZE DISTRIBUTION

GRAVEL:	23.3%	COARSE SAND:	32.4%
SAND:	76.3%	MEDIUM SAND:	16.3%
MUD:	0.4%	FINE SAND:	1.8%
		V FINE SAND:	0.6%
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:	10.5%	FINE SILT:	0.0%
V FINE GRAVEL:	12.8%	V FINE SILT:	0.0%
V COARSE SAND:	25.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1700.5	1064.2	-0.090	1079.9	-0.111	Very Coarse Sand
SORTING (σ):	1678.3	2.478	1.309	2.559	1.356	Poorly Sorted
SKEWNESS (Sk):	1.665	0.069	-0.069	0.172	-0.172	Coarse Skewed
KURTOSIS (K):	4.691	2.955	2.955	1.027	1.027	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **609**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

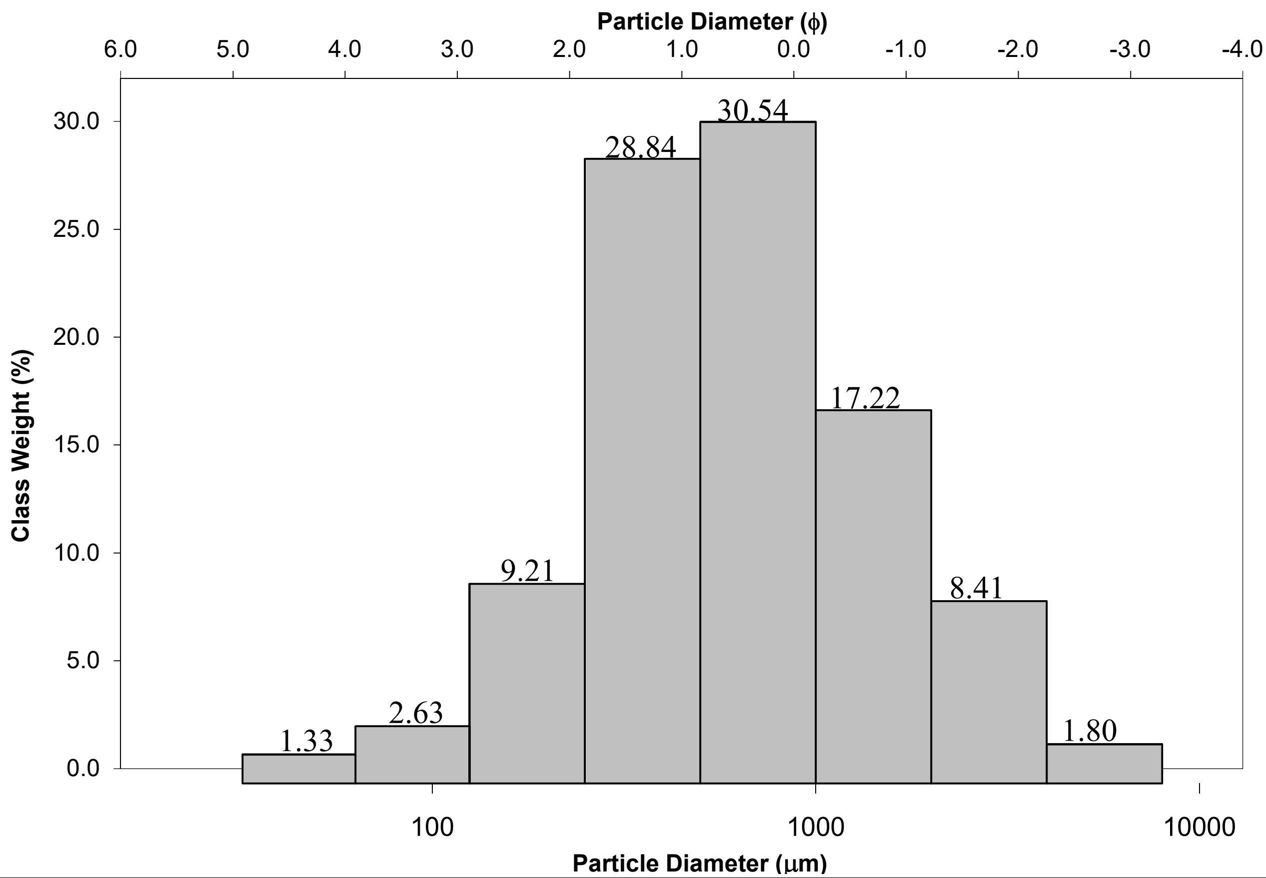
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	197.6	-1.026
MEDIAN or D_{50}:	599.7	0.738
D_{90}:	2036.6	2.339
(D_{90} / D_{10}):	10.31	-2.279
(D_{90} - D_{10}):	1839.0	3.365
(D_{75} / D_{25}):	3.320	-11.152
(D_{75} - D_{25}):	771.3	1.731

GRAIN SIZE DISTRIBUTION

GRAVEL:	10.2%	COARSE SAND:	30.6%
SAND:	88.5%	MEDIUM SAND:	28.9%
MUD:	1.3%	FINE SAND:	9.2%
		V FINE SAND:	2.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.3%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.8%	FINE SILT:	0.0%
V FINE GRAVEL:	8.4%	V FINE SILT:	0.0%
V COARSE SAND:	17.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	977.0	612.2	0.708	633.8	0.658	Coarse Sand
SORTING (σ):	1027.6	2.485	1.313	2.502	1.323	Poorly Sorted
SKEWNESS (Sk):	2.642	-0.056	0.056	0.070	-0.070	Symmetrical
KURTOSIS (K):	11.66	3.206	3.206	1.066	1.066	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **610**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Fine Gravel

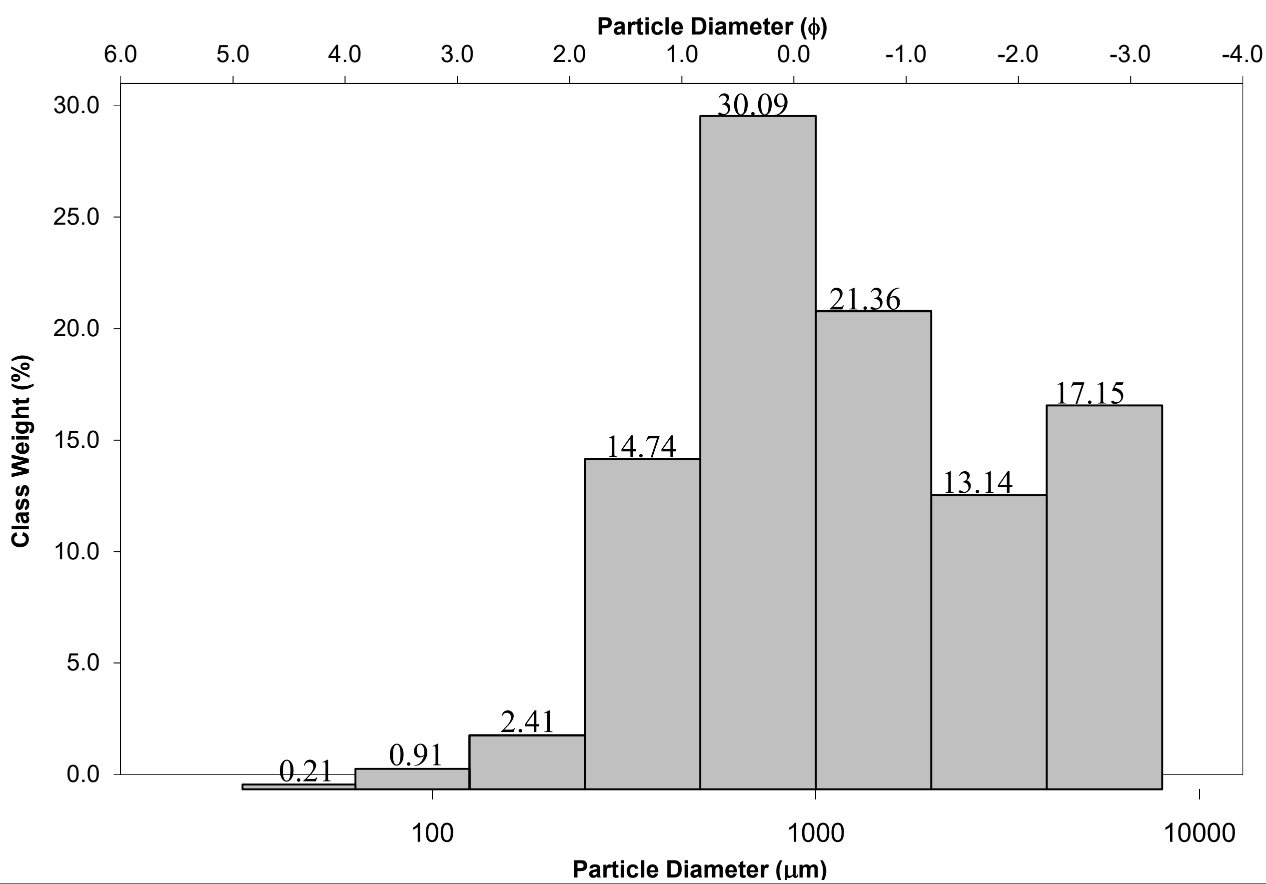
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	339.2	-2.417
MEDIAN or D_{50}:	1055.2	-0.077
D_{90}:	5340.4	1.560
(D_{90} / D_{10}):	15.75	-0.645
$(D_{90} - D_{10})$:	5001.3	3.977
(D_{75} / D_{25}):	4.527	-0.553
$(D_{75} - D_{25})$:	2059.9	2.179

GRAIN SIZE DISTRIBUTION

GRAVEL:	30.3%	COARSE SAND:	30.1%
SAND:	69.5%	MEDIUM SAND:	14.7%
MUD:	0.2%	FINE SAND:	2.4%
		V FINE SAND:	0.9%
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:	17.2%	FINE SILT:	0.0%
V FINE GRAVEL:	13.1%	V FINE SILT:	0.0%
V COARSE SAND:	21.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	2030.2	1197.8	-0.260	1257.5	-0.331	Very Coarse Sand
SORTING (σ):	1976.7	2.705	1.436	2.835	1.503	Poorly Sorted
SKEWNESS (Sk):	1.202	0.016	-0.016	0.189	-0.189	Coarse Skewed
KURTOSIS (K):	2.953	2.435	2.435	0.867	0.867	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **611**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

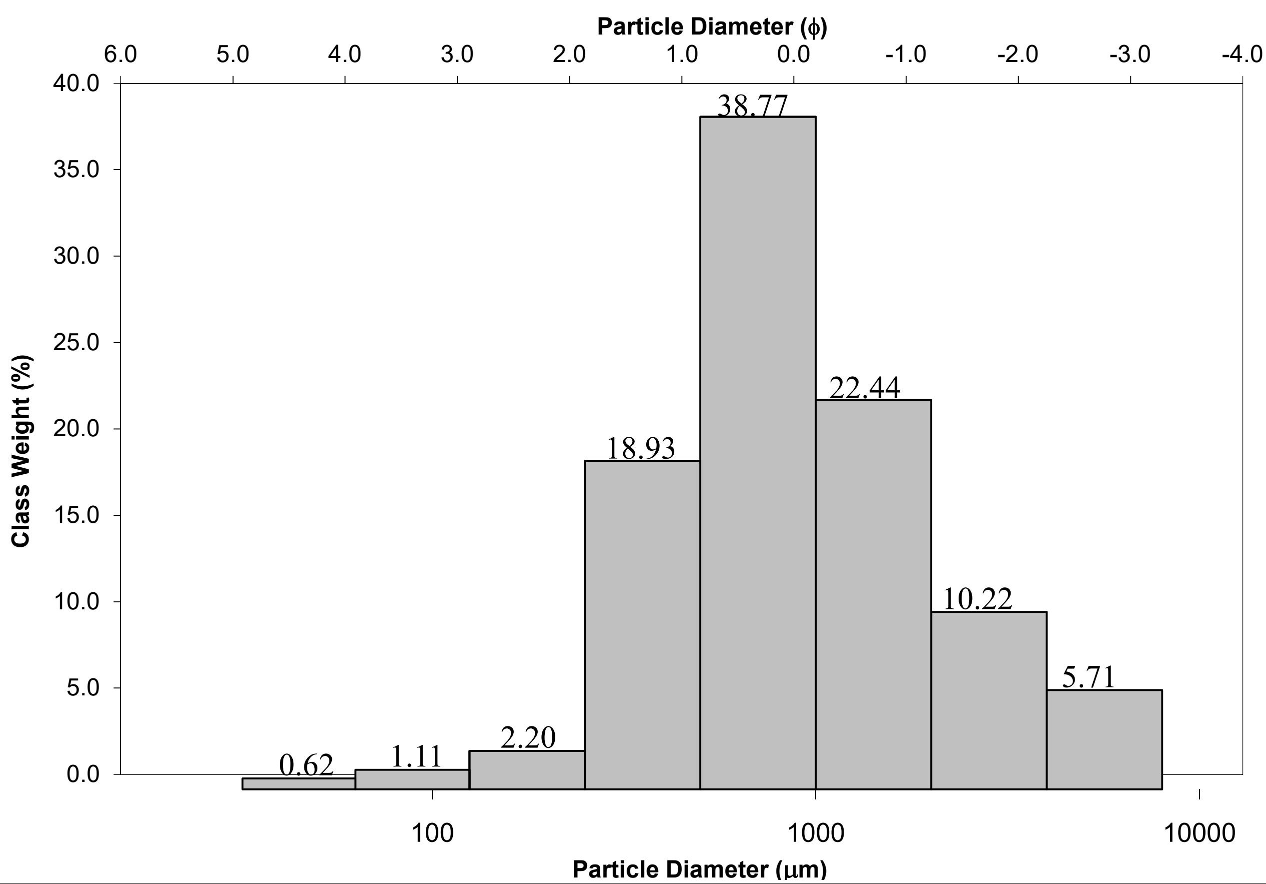
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	312.4	-1.580
MEDIAN or D_{50}:	812.4	0.300
D_{90}:	2990.5	1.678
(D_{90} / D_{10}):	9.571	-1.062
$(D_{90} - D_{10})$:	2678.1	3.259
(D_{75} / D_{25}):	2.909	-1.585
$(D_{75} - D_{25})$:	991.9	1.540

GRAIN SIZE DISTRIBUTION

GRAVEL:	15.9%	COARSE SAND:	38.8%
SAND:	83.5%	MEDIUM SAND:	18.9%
MUD:	0.6%	FINE SAND:	2.2%
		V FINE SAND:	1.1%
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:	5.7%	FINE SILT:	0.0%
V FINE GRAVEL:	10.2%	V FINE SILT:	0.0%
V COARSE SAND:	22.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1353.3	876.5	0.190	857.7	0.221	Coarse Sand
SORTING (σ):	1376.7	2.352	1.234	2.307	1.206	Poorly Sorted
SKEWNESS (Sk):	2.244	0.053	-0.053	0.146	-0.146	Coarse Skewed
KURTOSIS (K):	7.709	3.626	3.626	1.082	1.082	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **612**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

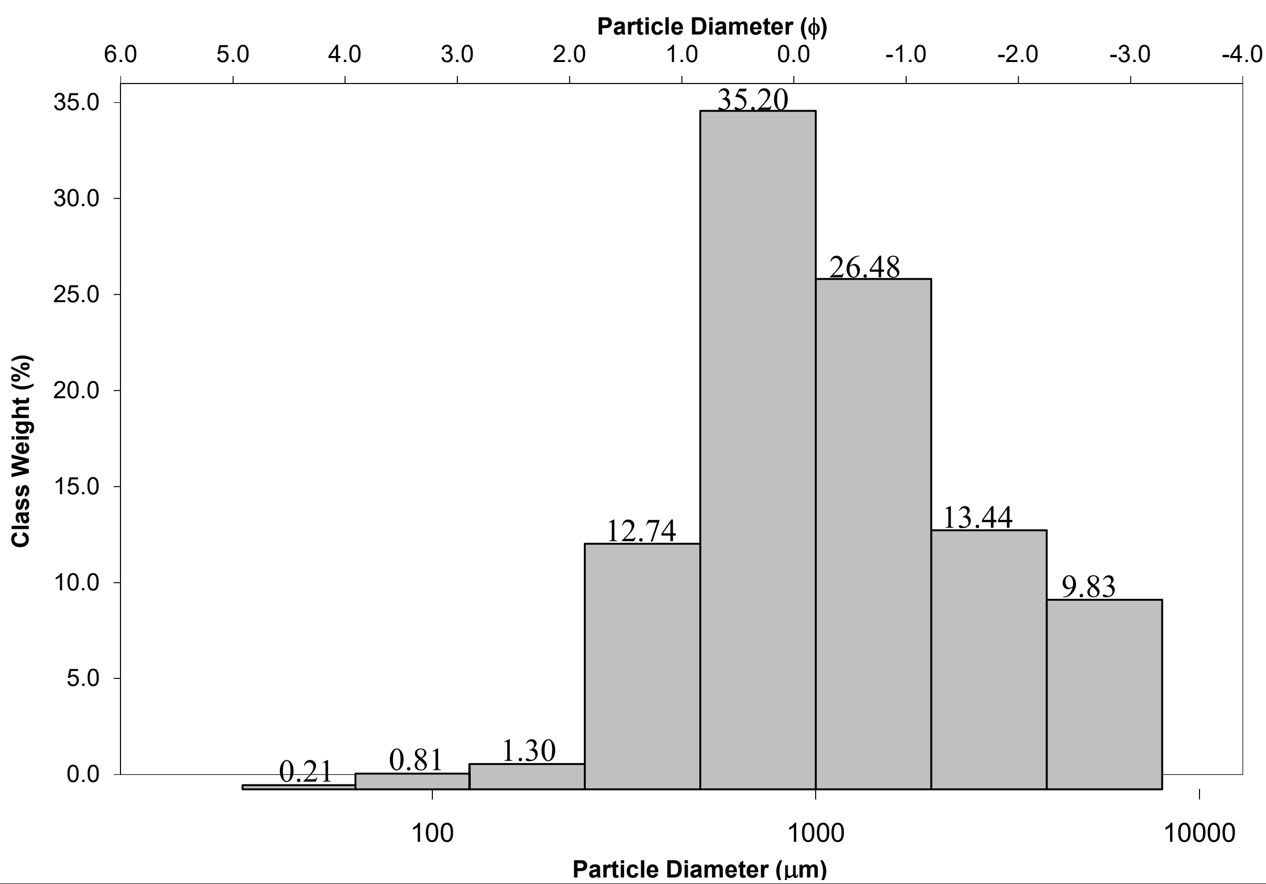
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	380.0	-1.987
MEDIAN or D_{50}:	995.1	0.007
D_{90}:	3965.0	1.396
(D_{90} / D_{10}):	10.44	-0.702
$(D_{90} - D_{10})$:	3585.0	3.383
(D_{75} / D_{25}):	3.142	-0.767
$(D_{75} - D_{25})$:	1303.2	1.652

GRAIN SIZE DISTRIBUTION

GRAVEL:	23.3%	COARSE SAND:	35.2%
SAND:	76.5%	MEDIUM SAND:	12.7%
MUD:	0.2%	FINE SAND:	1.3%
		V FINE SAND:	0.8%
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:	9.8%	FINE SILT:	0.0%
V FINE GRAVEL:	13.4%	V FINE SILT:	0.0%
V COARSE SAND:	26.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1705.3	1104.2	-0.143	1138.4	-0.187	Very Coarse Sand
SORTING (σ):	1628.7	2.375	1.248	2.423	1.277	Poorly Sorted
SKEWNESS (Sk):	1.708	0.078	-0.078	0.200	-0.200	Coarse Skewed
KURTOSIS (K):	4.925	3.068	3.068	1.062	1.062	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **613**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

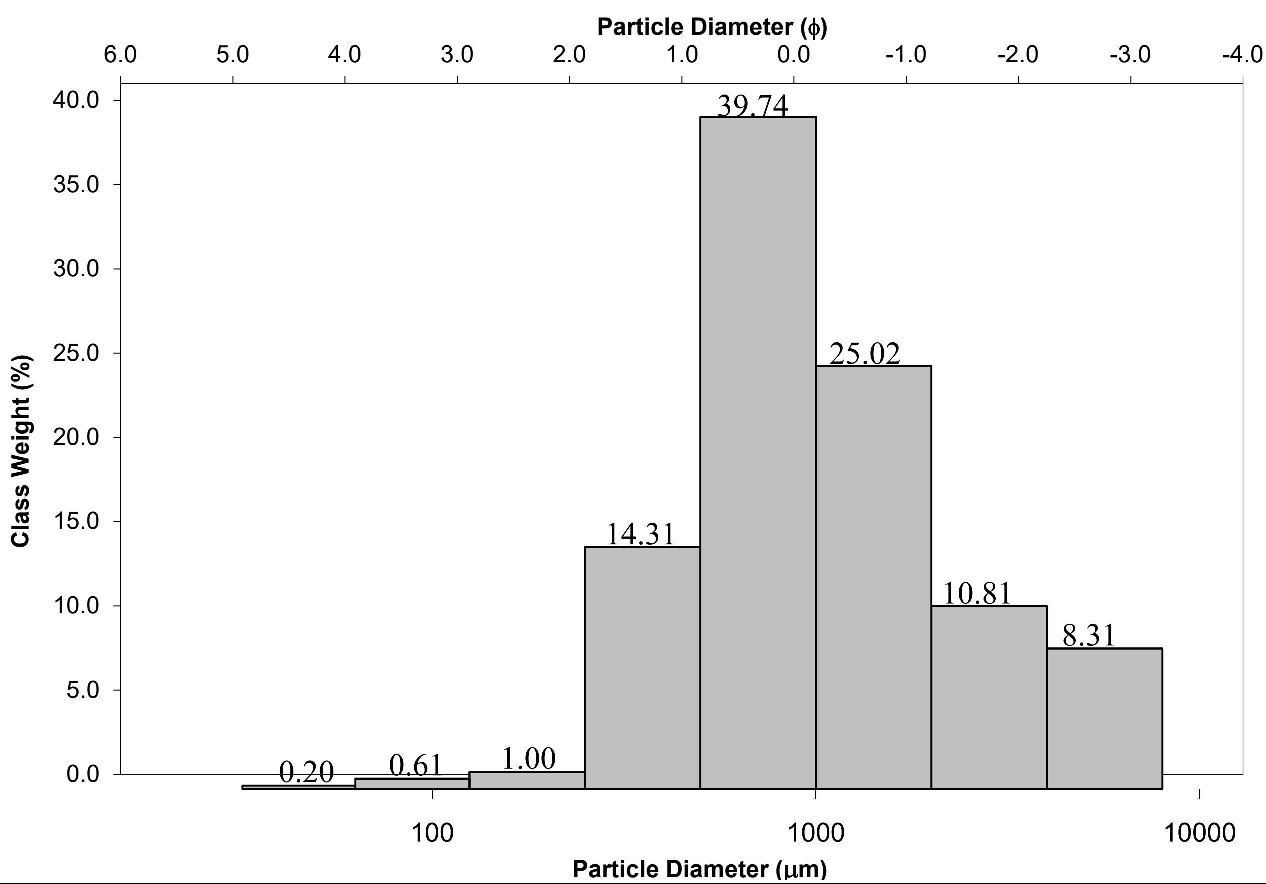
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	371.8	-1.844
MEDIAN or D_{50}:	902.9	0.147
D_{90}:	3588.8	1.427
(D_{90} / D_{10}):	9.652	-0.774
$(D_{90} - D_{10})$:	3217.0	3.271
(D_{75} / D_{25}):	2.911	-1.015
$(D_{75} - D_{25})$:	1115.6	1.541

GRAIN SIZE DISTRIBUTION

GRAVEL:	19.1%	COARSE SAND:	39.7%
SAND:	80.7%	MEDIUM SAND:	14.3%
MUD:	0.2%	FINE SAND:	1.0%
		V FINE SAND:	0.6%
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:	8.3%	FINE SILT:	0.0%
V FINE GRAVEL:	10.8%	V FINE SILT:	0.0%
V COARSE SAND:	25.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1552.5	1018.6	-0.027	1031.2	-0.044	Very Coarse Sand
SORTING (σ):	1536.5	2.285	1.192	2.308	1.207	Poorly Sorted
SKEWNESS (Sk):	1.970	0.269	-0.269	0.235	-0.235	Coarse Skewed
KURTOSIS (K):	6.009	3.262	3.262	1.110	1.110	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **614**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Fine Gravelly Coarse Sand

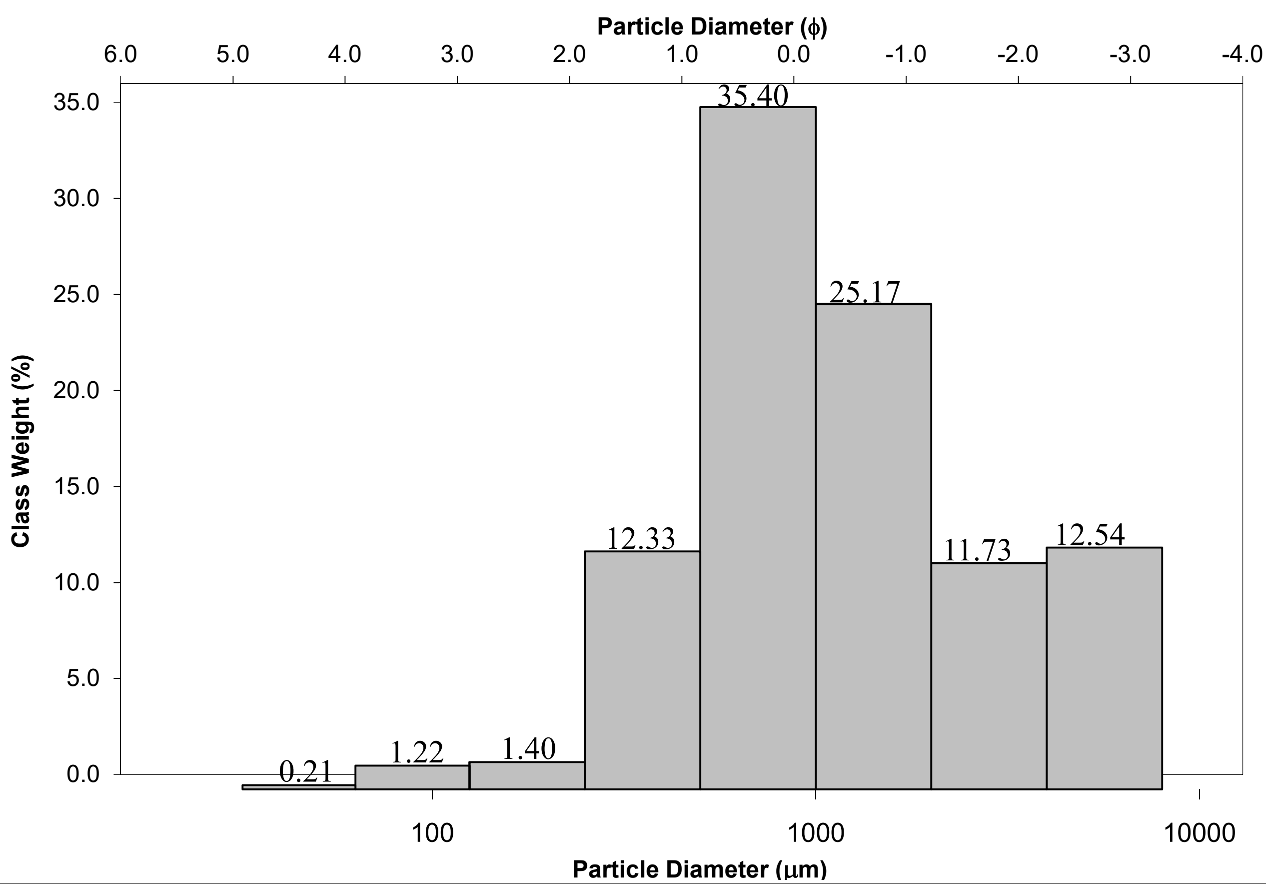
	μm	φ
MODE 1:	750.0	0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	374.5	-2.202
MEDIAN or D_{50}:	989.3	0.016
D_{90}:	4602.4	1.417
(D_{90} / D_{10}):	12.29	-0.643
$(D_{90} - D_{10})$:	4228.0	3.619
(D_{75} / D_{25}):	3.233	-0.743
$(D_{75} - D_{25})$:	1354.0	1.693

GRAIN SIZE DISTRIBUTION

GRAVEL:	24.3%	COARSE SAND:	35.4%
SAND:	75.5%	MEDIUM SAND:	12.3%
MUD:	0.2%	FINE SAND:	1.4%
		V FINE SAND:	1.2%
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:	12.5%	FINE SILT:	0.0%
V FINE GRAVEL:	11.7%	V FINE SILT:	0.0%
V COARSE SAND:	25.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1797.6	1122.8	-0.167	1179.2	-0.238	Very Coarse Sand
SORTING (σ):	1766.9	2.484	1.313	2.532	1.340	Poorly Sorted
SKEWNESS (Sk):	1.561	0.064	-0.064	0.233	-0.233	Coarse Skewed
KURTOSIS (K):	4.155	3.001	3.001	1.071	1.071	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **616**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

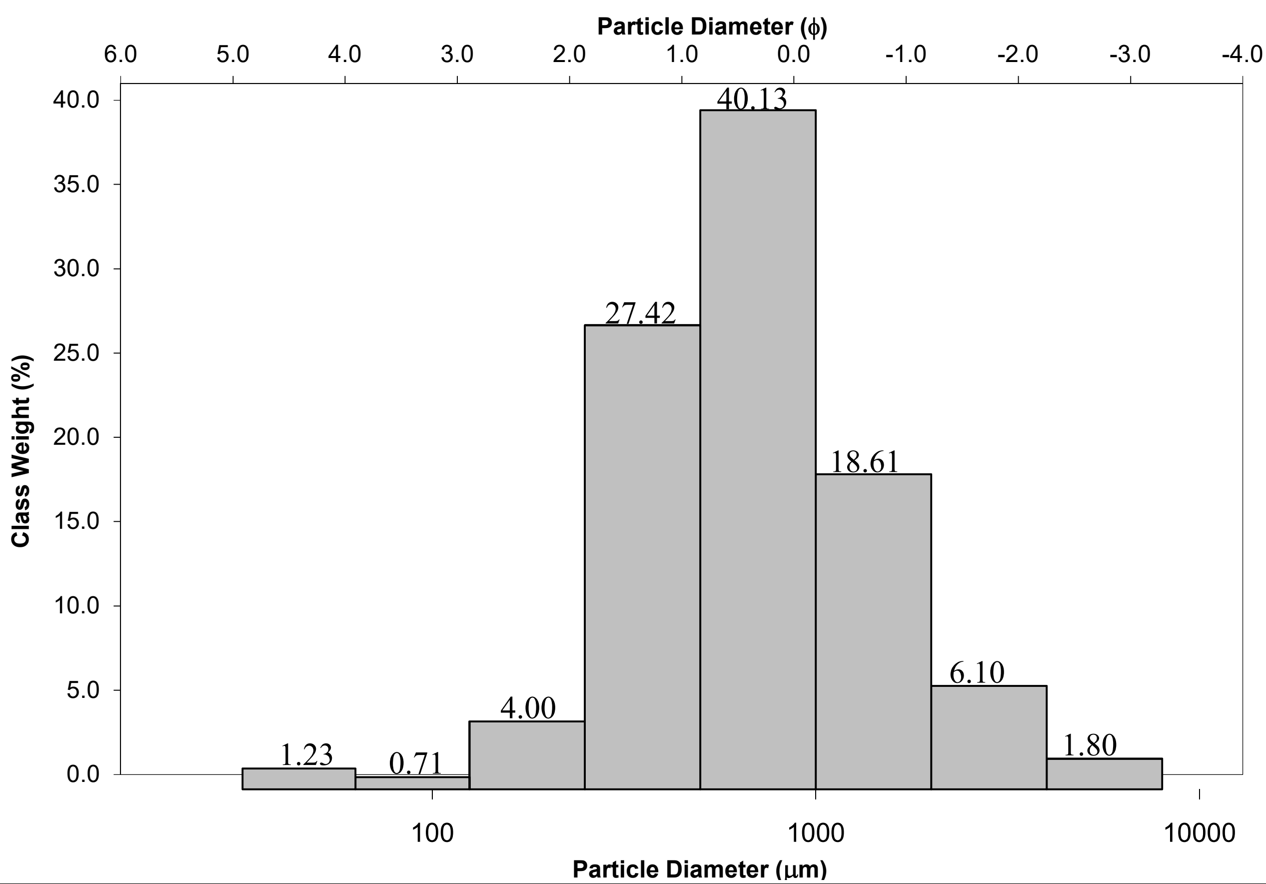
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	277.3	-0.888
MEDIAN or D_{50}:	666.7	0.585
D_{90}:	1850.1	1.851
(D_{90} / D_{10}):	6.673	-2.085
$(D_{90} - D_{10})$:	1572.9	2.738
(D_{75} / D_{25}):	2.613	-15.902
$(D_{75} - D_{25})$:	653.4	1.386

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.9%	COARSE SAND:	40.1%
SAND:	90.9%	MEDIUM SAND:	27.4%
MUD:	1.2%	FINE SAND:	4.0%
		V FINE SAND:	0.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.2%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.8%	FINE SILT:	0.0%
V FINE GRAVEL:	6.1%	V FINE SILT:	0.0%
V COARSE SAND:	18.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	983.2	678.0	0.561	682.8	0.550	Coarse Sand
SORTING (σ):	957.2	2.188	1.130	2.159	1.110	Poorly Sorted
SKEWNESS (Sk):	3.078	-0.100	0.100	0.080	-0.080	Symmetrical
KURTOSIS (K):	14.90	4.324	4.324	1.095	1.095	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **617**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

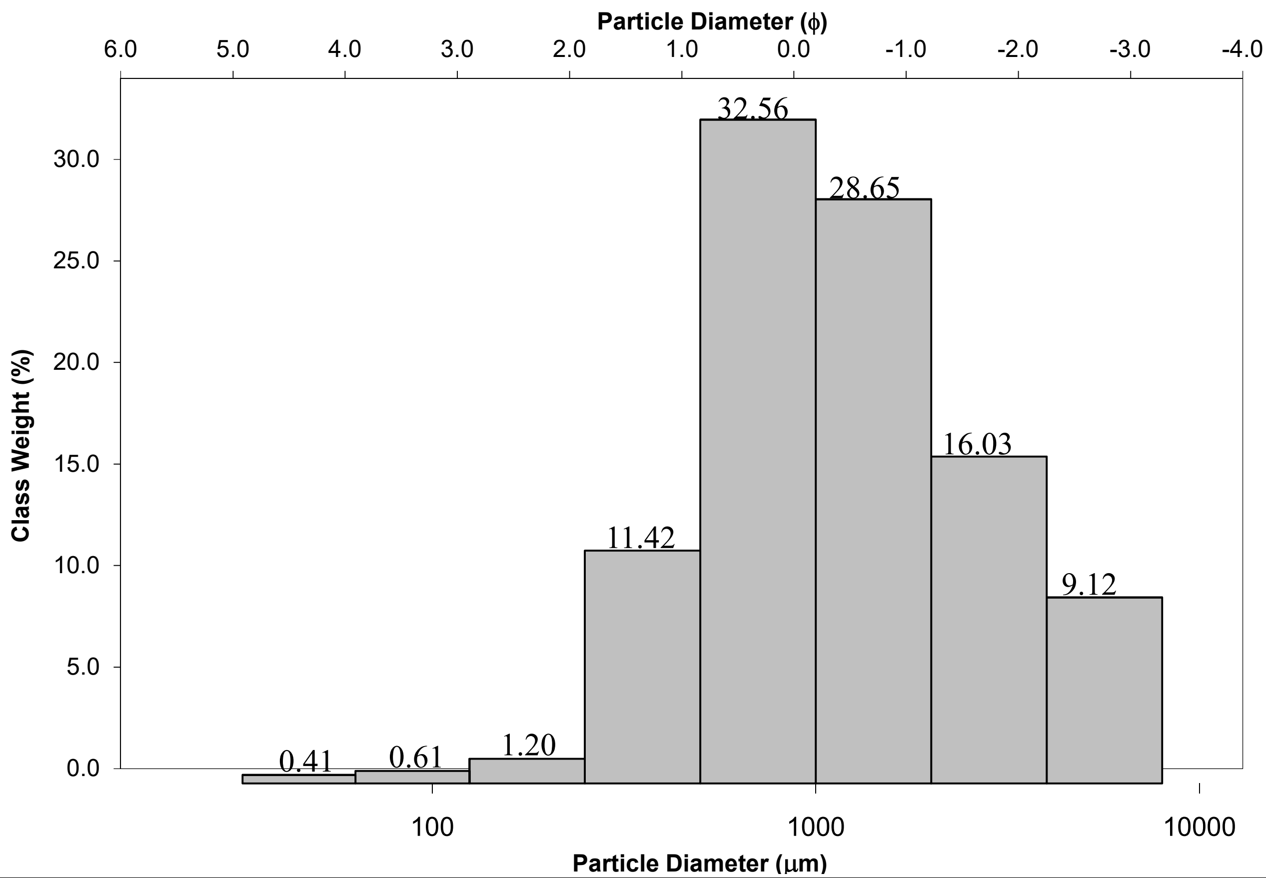
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	401.2	-1.945
MEDIAN or D_{50}:	1096.5	-0.133
D_{90}:	3850.4	1.318
(D_{90} / D_{10}):	9.597	-0.677
$(D_{90} - D_{10})$:	3449.2	3.263
(D_{75} / D_{25}):	3.160	-0.645
$(D_{75} - D_{25})$:	1376.1	1.660

GRAIN SIZE DISTRIBUTION

GRAVEL:	25.2%	COARSE SAND:	32.6%
SAND:	74.5%	MEDIUM SAND:	11.4%
MUD:	0.4%	FINE SAND:	1.2%
		V FINE SAND:	0.6%
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:	9.1%	FINE SILT:	0.0%
V FINE GRAVEL:	16.0%	V FINE SILT:	0.0%
V COARSE SAND:	28.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1748.0	1155.5	-0.209	1196.5	-0.259	Very Coarse Sand
SORTING (σ):	1585.7	2.354	1.235	2.398	1.262	Poorly Sorted
SKEWNESS (Sk):	1.657	-0.102	0.102	0.127	-0.127	Coarse Skewed
KURTOSIS (K):	4.916	3.318	3.318	1.039	1.039	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **709**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

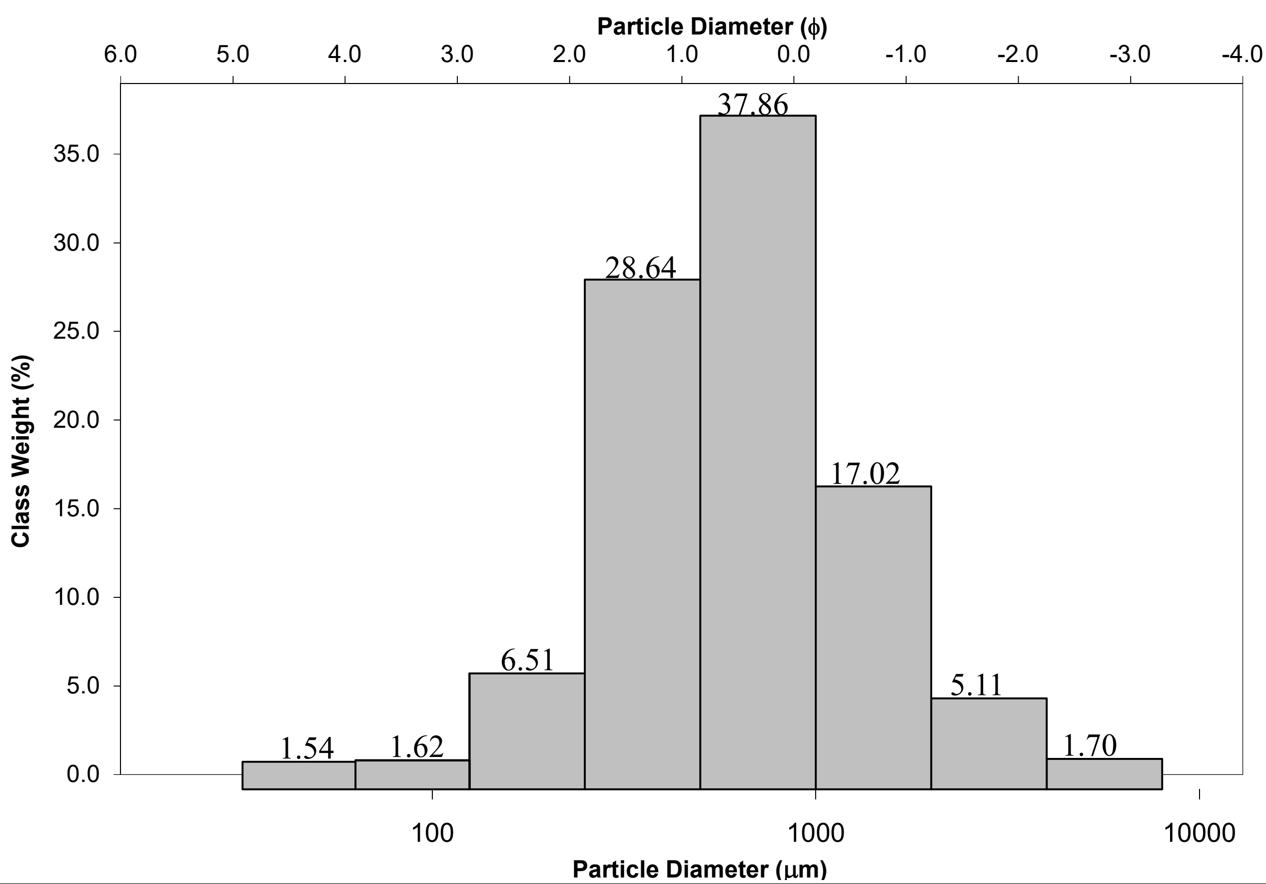
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	252.3	-0.813
MEDIAN or D_{50}:	619.6	0.690
D_{90}:	1756.8	1.987
(D_{90} / D_{10}):	6.963	-2.444
$(D_{90} - D_{10})$:	1504.5	2.800
(D_{75} / D_{25}):	2.700	48.10
$(D_{75} - D_{25})$:	616.5	1.433

GRAIN SIZE DISTRIBUTION

GRAVEL:	6.8%	COARSE SAND:	37.9%
SAND:	91.7%	MEDIUM SAND:	28.7%
MUD:	1.5%	FINE SAND:	6.5%
		V FINE SAND:	1.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.5%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.7%	FINE SILT:	0.0%
V FINE GRAVEL:	5.1%	V FINE SILT:	0.0%
V COARSE SAND:	17.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	917.0	615.2	0.701	628.9	0.669	Coarse Sand
SORTING (σ):	933.5	2.282	1.190	2.258	1.175	Poorly Sorted
SKEWNESS (Sk):	3.247	-0.168	0.168	0.018	-0.018	Symmetrical
KURTOSIS (K):	16.35	4.075	4.075	1.162	1.162	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **710**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

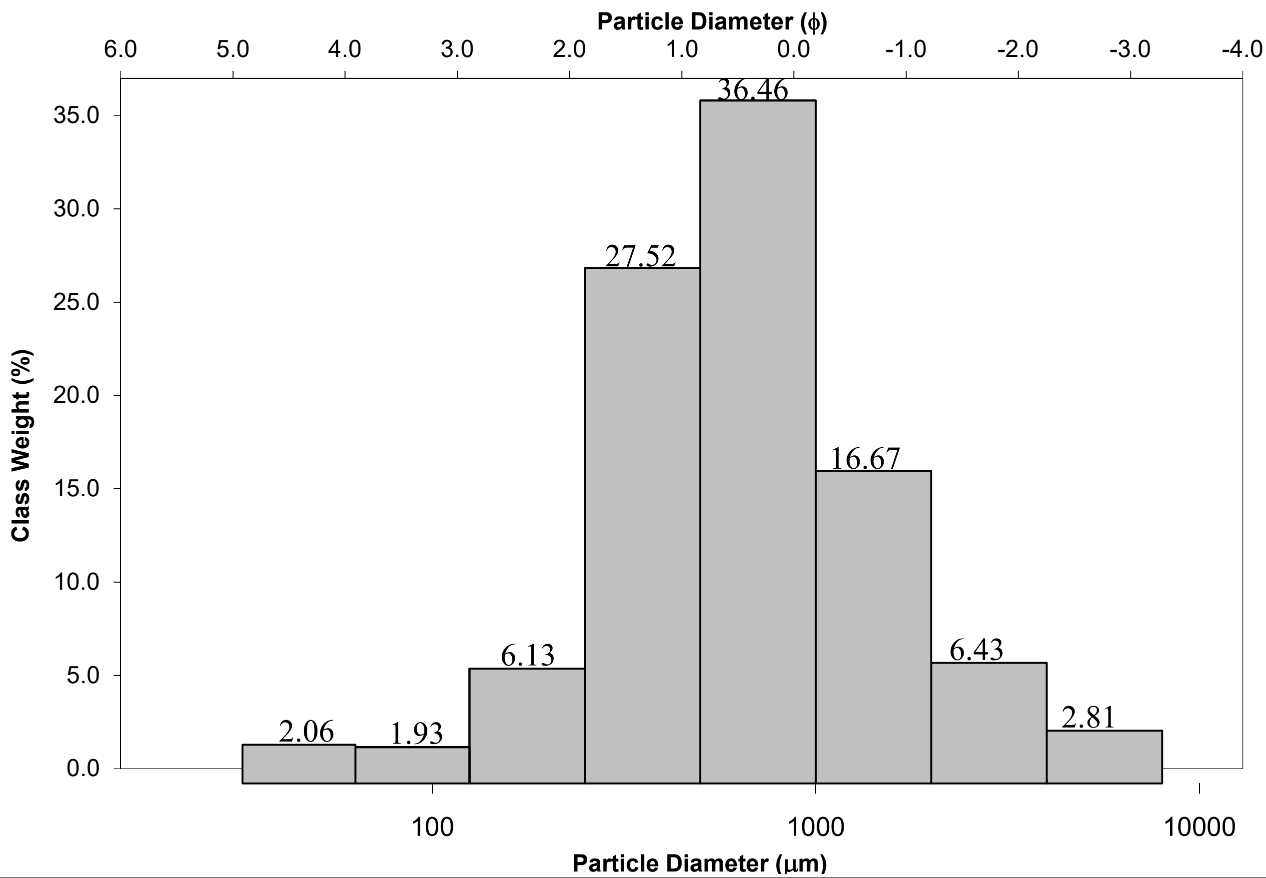
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	248.6	-0.955
MEDIAN or D_{50}:	633.0	0.660
D_{90}:	1938.3	2.008
(D_{90} / D_{10}):	7.798	-2.103
(D_{90} - D_{10}):	1689.8	2.963
(D_{75} / D_{25}):	2.854	-26.149
(D_{75} - D_{25}):	675.2	1.513

GRAIN SIZE DISTRIBUTION

GRAVEL:	9.2%	COARSE SAND:	36.5%
SAND:	88.8%	MEDIUM SAND:	27.5%
MUD:	2.0%	FINE SAND:	6.1%
		V FINE SAND:	1.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.8%	FINE SILT:	0.0%
V FINE GRAVEL:	6.4%	V FINE SILT:	0.0%
V COARSE SAND:	16.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1003.2	635.0	0.655	652.4	0.616	Coarse Sand
SORTING (σ):	1098.8	2.445	1.290	2.419	1.274	Poorly Sorted
SKEWNESS (Sk):	2.943	-0.151	0.151	0.045	-0.045	Symmetrical
KURTOSIS (K):	12.81	3.924	3.924	1.215	1.215	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **711**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

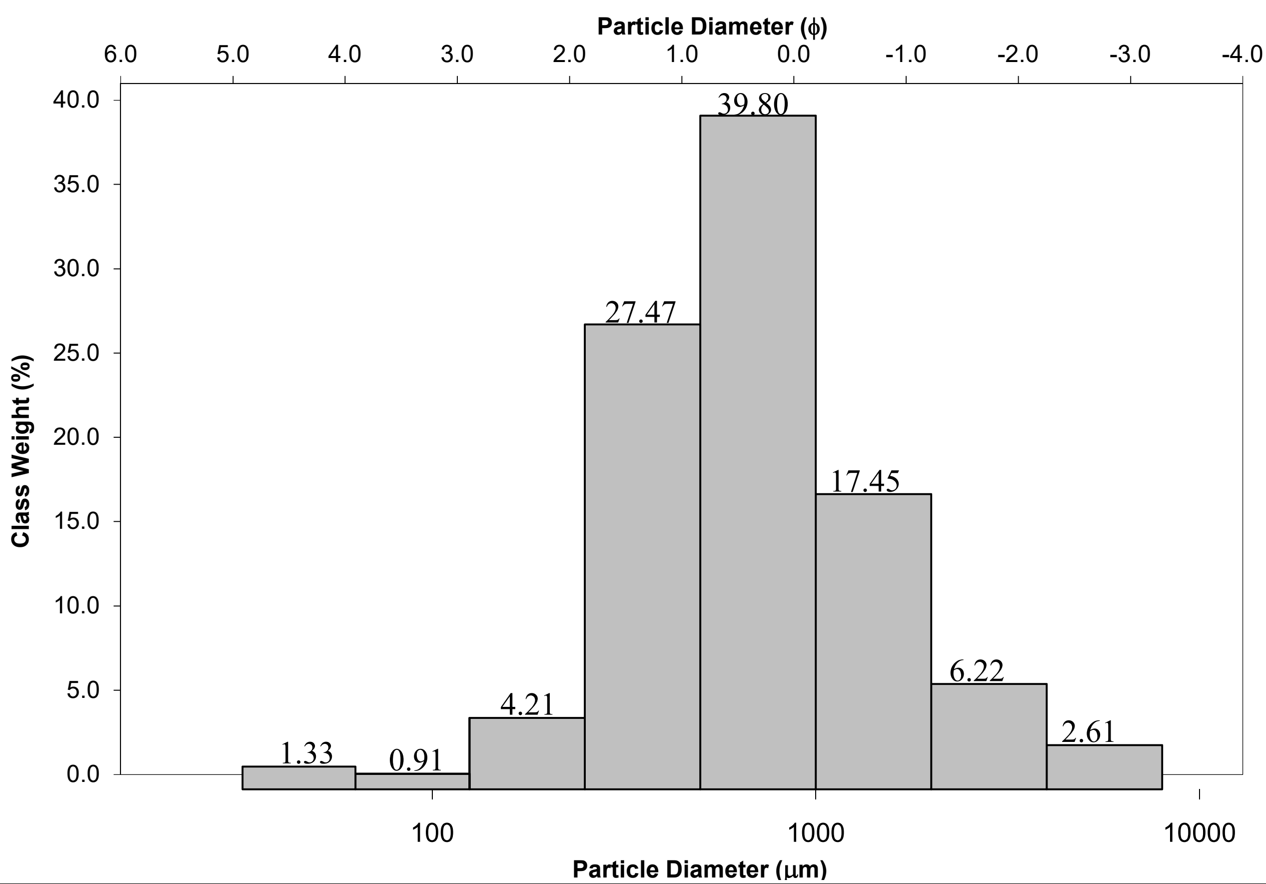
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	273.6	-0.933
MEDIAN or D_{50}:	661.7	0.596
D_{90}:	1908.9	1.870
(D_{90} / D_{10}):	6.976	-2.004
$(D_{90} - D_{10})$:	1635.3	2.802
(D_{75} / D_{25}):	2.634	-18.067
$(D_{75} - D_{25})$:	652.7	1.397

GRAIN SIZE DISTRIBUTION

GRAVEL:	8.8%	COARSE SAND:	39.8%
SAND:	89.9%	MEDIUM SAND:	27.5%
MUD:	1.3%	FINE SAND:	4.2%
		V FINE SAND:	0.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.3%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	2.6%	FINE SILT:	0.0%
V FINE GRAVEL:	6.2%	V FINE SILT:	0.0%
V COARSE SAND:	17.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1015.9	677.9	0.561	681.7	0.553	Coarse Sand
SORTING (σ):	1059.9	2.261	1.177	2.233	1.159	Poorly Sorted
SKEWNESS (Sk):	3.033	-0.028	0.028	0.088	-0.088	Symmetrical
KURTOSIS (K):	13.59	4.264	4.264	1.159	1.159	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **712**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

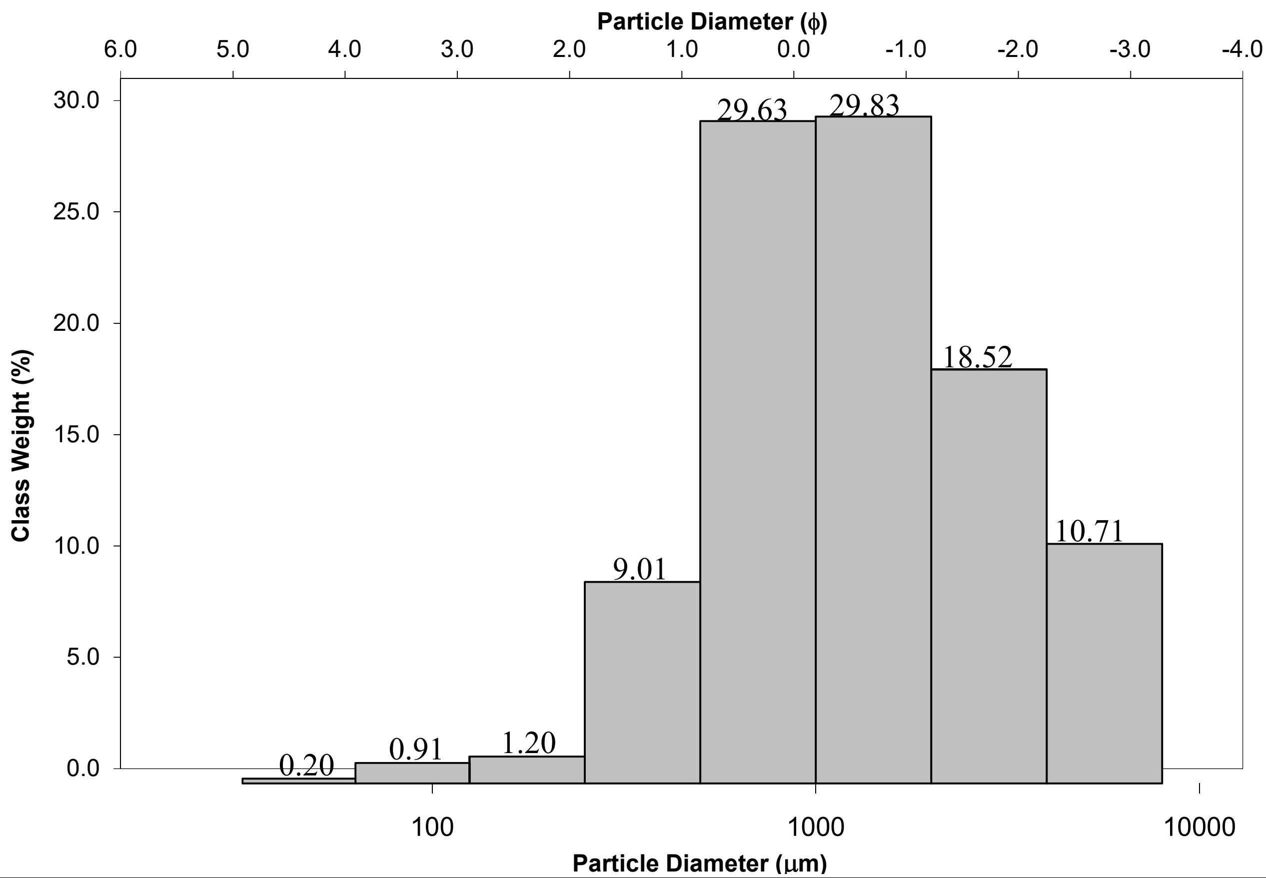
	μm	ϕ
MODE 1:	1500.0	-0.500
MODE 2:		
MODE 3:		
D_{10}:	452.0	-2.066
MEDIAN or D_{50}:	1234.3	-0.304
D_{90}:	4188.3	1.146
(D_{90} / D_{10}):	9.266	-0.554
$(D_{90} - D_{10})$:	3736.3	3.212
(D_{75} / D_{25}):	3.402	-0.438
$(D_{75} - D_{25})$:	1654.3	1.766

GRAIN SIZE DISTRIBUTION

GRAVEL:	29.2%	COARSE SAND:	29.6%
SAND:	70.6%	MEDIUM SAND:	9.0%
MUD:	0.2%	FINE SAND:	1.2%
		V FINE SAND:	0.9%
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:	10.7%	FINE SILT:	0.0%
V FINE GRAVEL:	18.5%	V FINE SILT:	0.0%
V COARSE SAND:	29.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1904.8	1266.6	-0.341	1312.3	-0.392	Very Coarse Sand
SORTING (σ):	1656.8	2.368	1.244	2.429	1.281	Poorly Sorted
SKEWNESS (Sk):	1.467	-0.197	0.197	0.078	-0.078	Symmetrical
KURTOSIS (K):	4.199	3.201	3.201	0.982	0.982	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **713**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

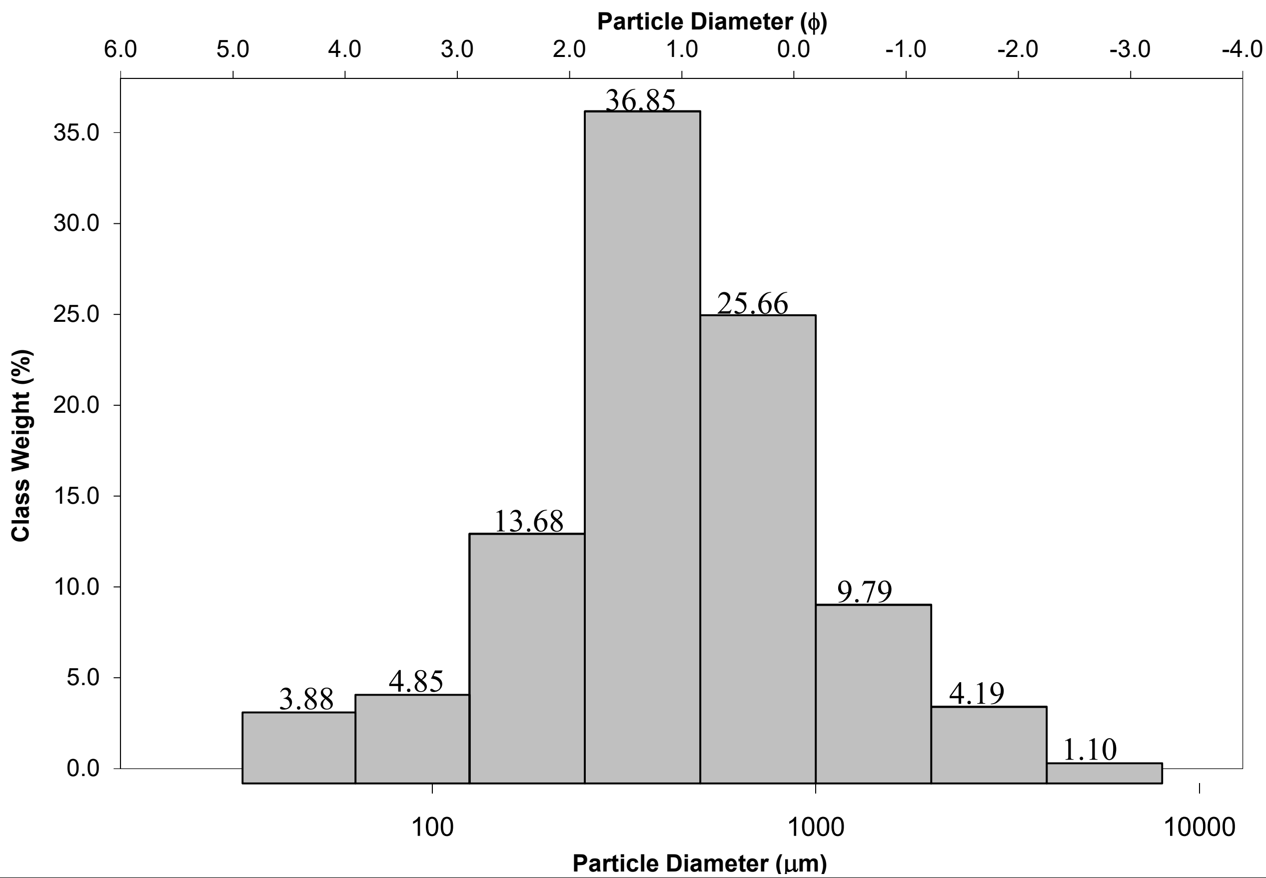
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	134.2	-0.520
MEDIAN or D_{50}:	420.6	1.249
D_{90}:	1434.4	2.898
(D_{90} / D_{10}):	10.69	-5.568
(D_{90} - D_{10}):	1300.2	3.418
(D_{75} / D_{25}):	2.911	5.002
(D_{75} - D_{25}):	502.7	1.542

GRAIN SIZE DISTRIBUTION

GRAVEL:	5.3%	COARSE SAND:	25.7%
SAND:	90.9%	MEDIUM SAND:	36.9%
MUD:	3.8%	FINE SAND:	13.7%
		V FINE SAND:	4.8%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.1%	FINE SILT:	0.0%
V FINE GRAVEL:	4.2%	V FINE SILT:	0.0%
V COARSE SAND:	9.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	702.1	428.4	1.223	421.0	1.248	Medium Sand
SORTING (σ):	838.6	2.528	1.338	2.523	1.335	Poorly Sorted
SKEWNESS (Sk):	3.632	-0.063	0.063	-0.017	0.017	Symmetrical
KURTOSIS (K):	20.02	3.511	3.511	1.279	1.279	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **714**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

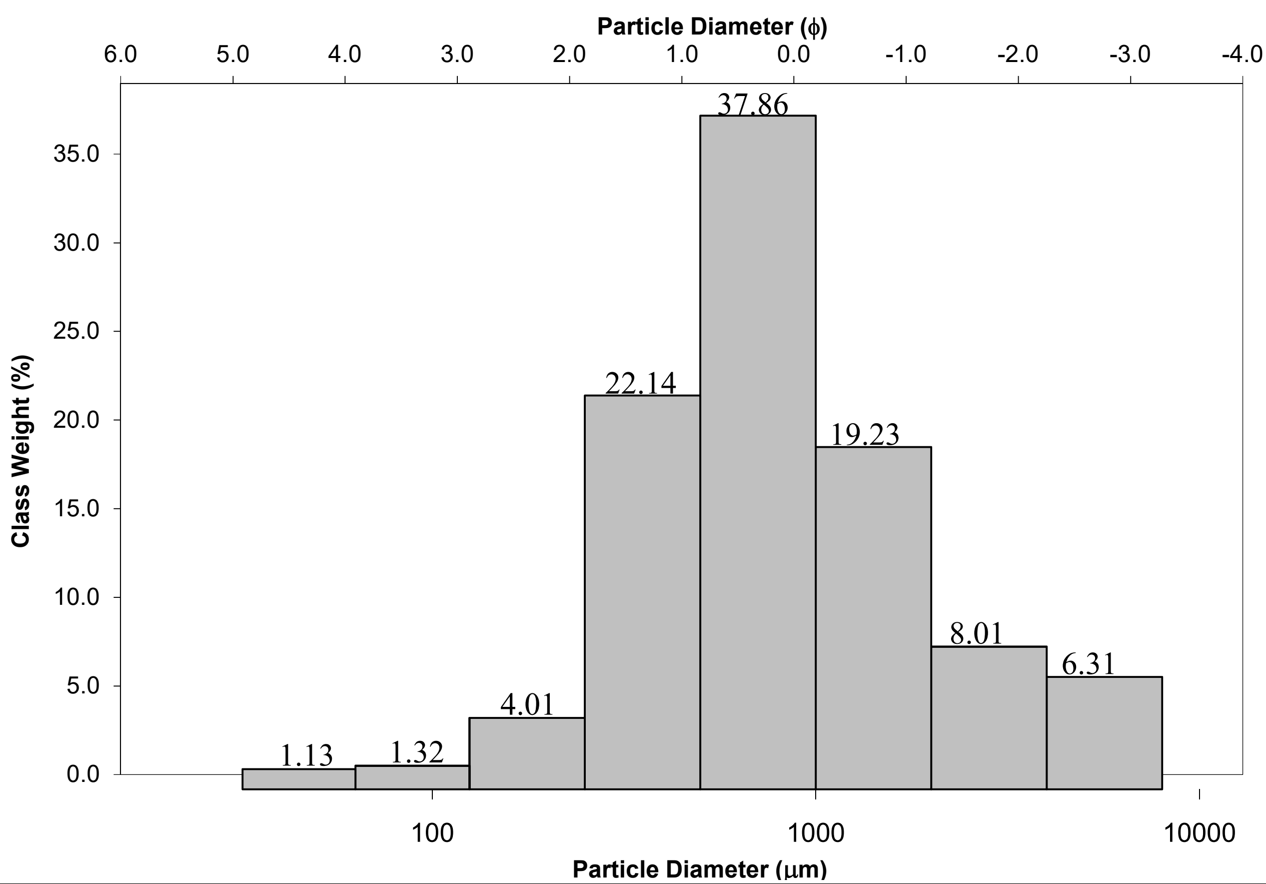
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	279.7	-1.540
MEDIAN or D_{50}:	740.3	0.434
D_{90}:	2907.9	1.838
(D_{90} / D_{10}):	10.40	-1.194
$(D_{90} - D_{10})$:	2628.2	3.378
(D_{75} / D_{25}):	3.044	-2.606
$(D_{75} - D_{25})$:	914.3	1.606

GRAIN SIZE DISTRIBUTION

GRAVEL:	14.3%	COARSE SAND:	37.9%
SAND:	84.6%	MEDIUM SAND:	22.1%
MUD:	1.1%	FINE SAND:	4.0%
		V FINE SAND:	1.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	6.3%	FINE SILT:	0.0%
V FINE GRAVEL:	8.0%	V FINE SILT:	0.0%
V COARSE SAND:	19.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1284.2	788.8	0.342	777.8	0.363	Coarse Sand
SORTING (σ):	1422.5	2.488	1.315	2.481	1.311	Poorly Sorted
SKEWNESS (Sk):	2.330	0.058	-0.058	0.122	-0.122	Coarse Skewed
KURTOSIS (K):	7.866	3.650	3.650	1.164	1.164	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **715**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

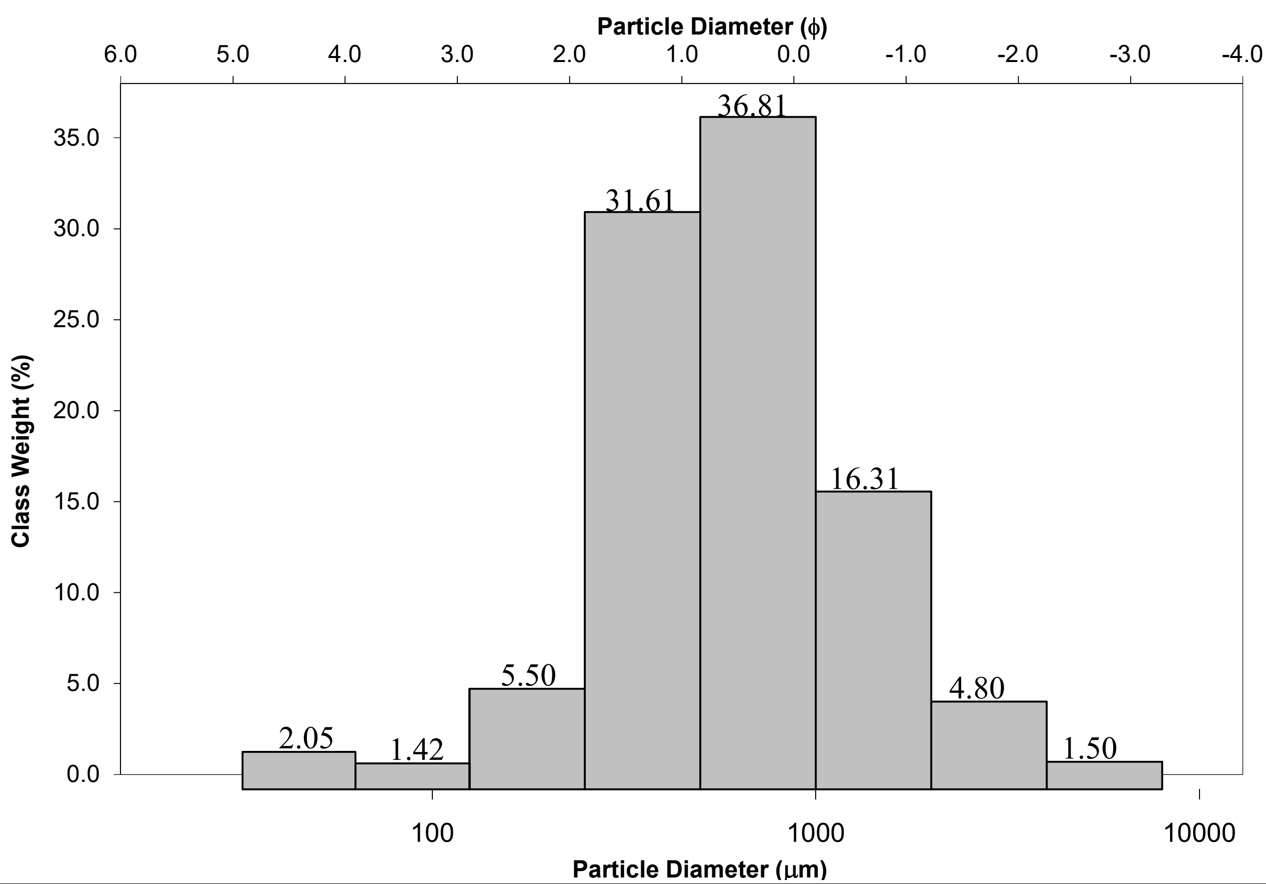
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	256.0	-0.774
MEDIAN or D_{50}:	597.4	0.743
D_{90}:	1709.6	1.966
(D_{90} / D_{10}):	6.677	-2.541
$(D_{90} - D_{10})$:	1453.5	2.739
(D_{75} / D_{25}):	2.688	23.11
$(D_{75} - D_{25})$:	600.6	1.427

GRAIN SIZE DISTRIBUTION

GRAVEL:	6.3%	COARSE SAND:	36.8%
SAND:	91.7%	MEDIUM SAND:	31.6%
MUD:	2.0%	FINE SAND:	5.5%
		V FINE SAND:	1.4%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	1.5%	FINE SILT:	0.0%
V FINE GRAVEL:	4.8%	V FINE SILT:	0.0%
V COARSE SAND:	16.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	886.5	597.2	0.744	613.7	0.704	Coarse Sand
SORTING (σ):	898.9	2.277	1.187	2.217	1.149	Poorly Sorted
SKEWNESS (Sk):	3.329	-0.235	0.235	0.033	-0.033	Symmetrical
KURTOSIS (K):	17.30	4.321	4.321	1.144	1.144	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **716** ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

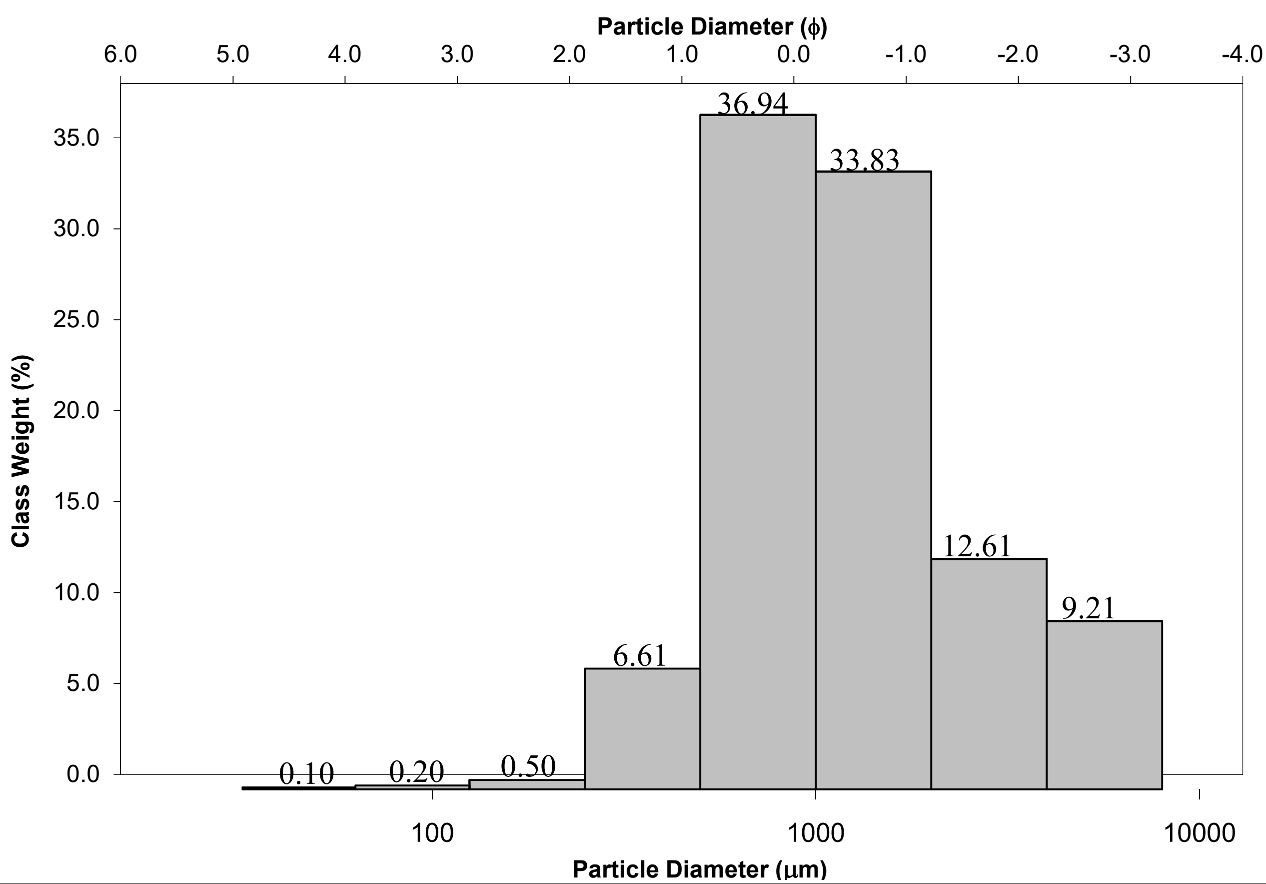
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	524.9	-1.937
MEDIAN or D_{50}:	1122.8	-0.167
D_{90}:	3829.9	0.930
(D_{90} / D_{10}):	7.296	-0.480
(D_{90} - D_{10}):	3305.0	2.867
(D_{75} / D_{25}):	2.694	-0.578
(D_{75} - D_{25}):	1178.3	1.430

GRAIN SIZE DISTRIBUTION

GRAVEL:	21.8%	COARSE SAND:	36.9%
SAND:	78.1%	MEDIUM SAND:	6.6%
MUD:	0.1%	FINE SAND:	0.5%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	9.2%	FINE SILT:	0.0%
V FINE GRAVEL:	12.6%	V FINE SILT:	0.0%
V COARSE SAND:	33.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1741.4	1214.9	-0.281	1220.2	-0.287	Very Coarse Sand
SORTING (σ):	1548.0	2.125	1.087	2.198	1.136	Poorly Sorted
SKEWNESS (Sk):	1.832	0.285	-0.285	0.180	-0.180	Coarse Skewed
KURTOSIS (K):	5.441	3.246	3.246	1.095	1.095	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **717**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

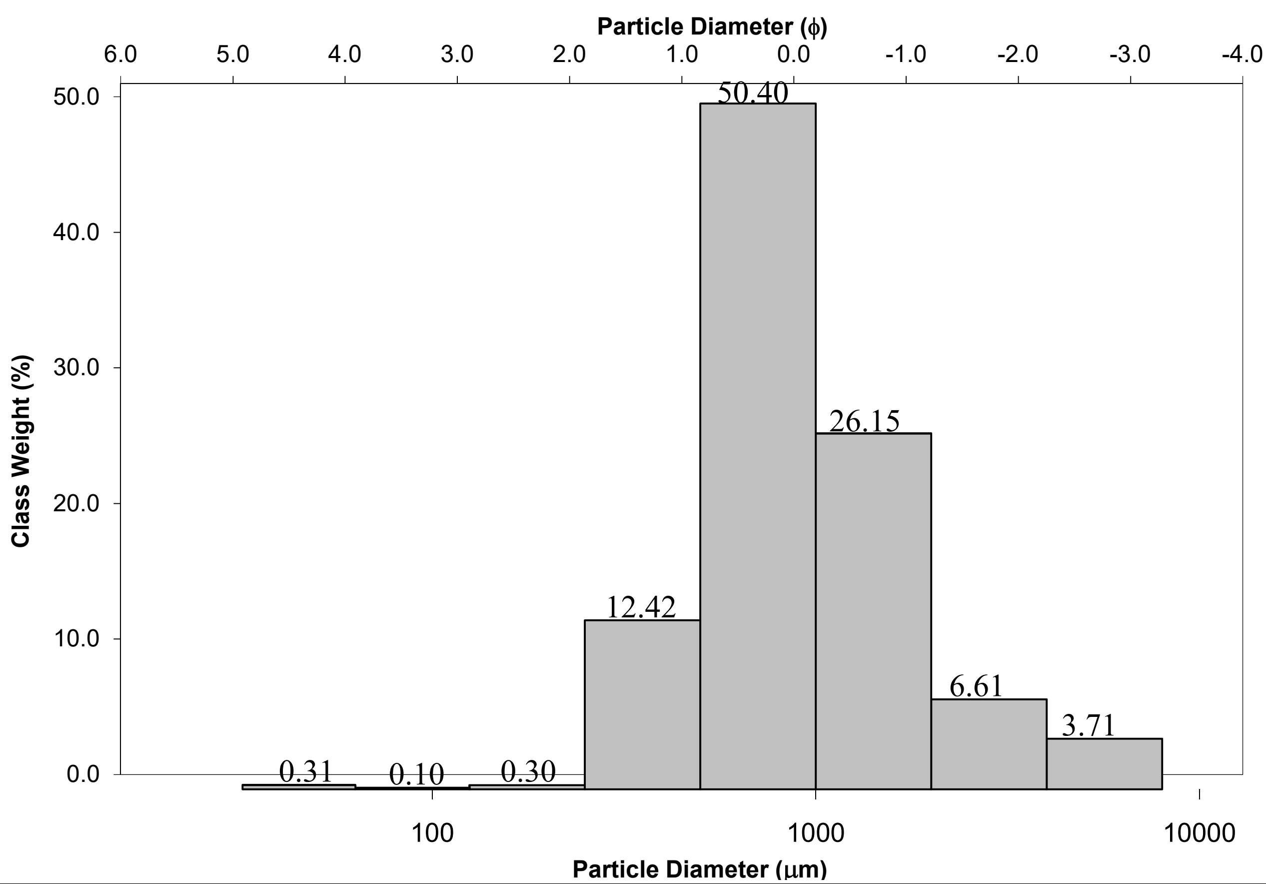
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	420.0	-1.048
MEDIAN or D_{50}:	830.2	0.268
D_{90}:	2068.4	1.252
(D_{90} / D_{10}):	4.925	-1.194
(D_{90} - D_{10}):	1648.4	2.300
(D_{75} / D_{25}):	2.302	-1.742
(D_{75} - D_{25}):	766.7	1.203

GRAIN SIZE DISTRIBUTION

GRAVEL:	10.3%	COARSE SAND:	50.4%
SAND:	89.4%	MEDIUM SAND:	12.4%
MUD:	0.3%	FINE SAND:	0.3%
		V FINE SAND:	0.1%
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:	3.7%	FINE SILT:	0.0%
V FINE GRAVEL:	6.6%	V FINE SILT:	0.0%
V COARSE SAND:	26.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1238.5	907.4	0.140	905.7	0.143	Coarse Sand
SORTING (σ):	1133.8	1.946	0.961	1.939	0.955	Moderately Sorted
SKEWNESS (Sk):	2.895	0.433	-0.433	0.208	-0.208	Coarse Skewed
KURTOSIS (K):	11.98	4.742	4.742	1.178	1.178	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **809**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Fine Gravel

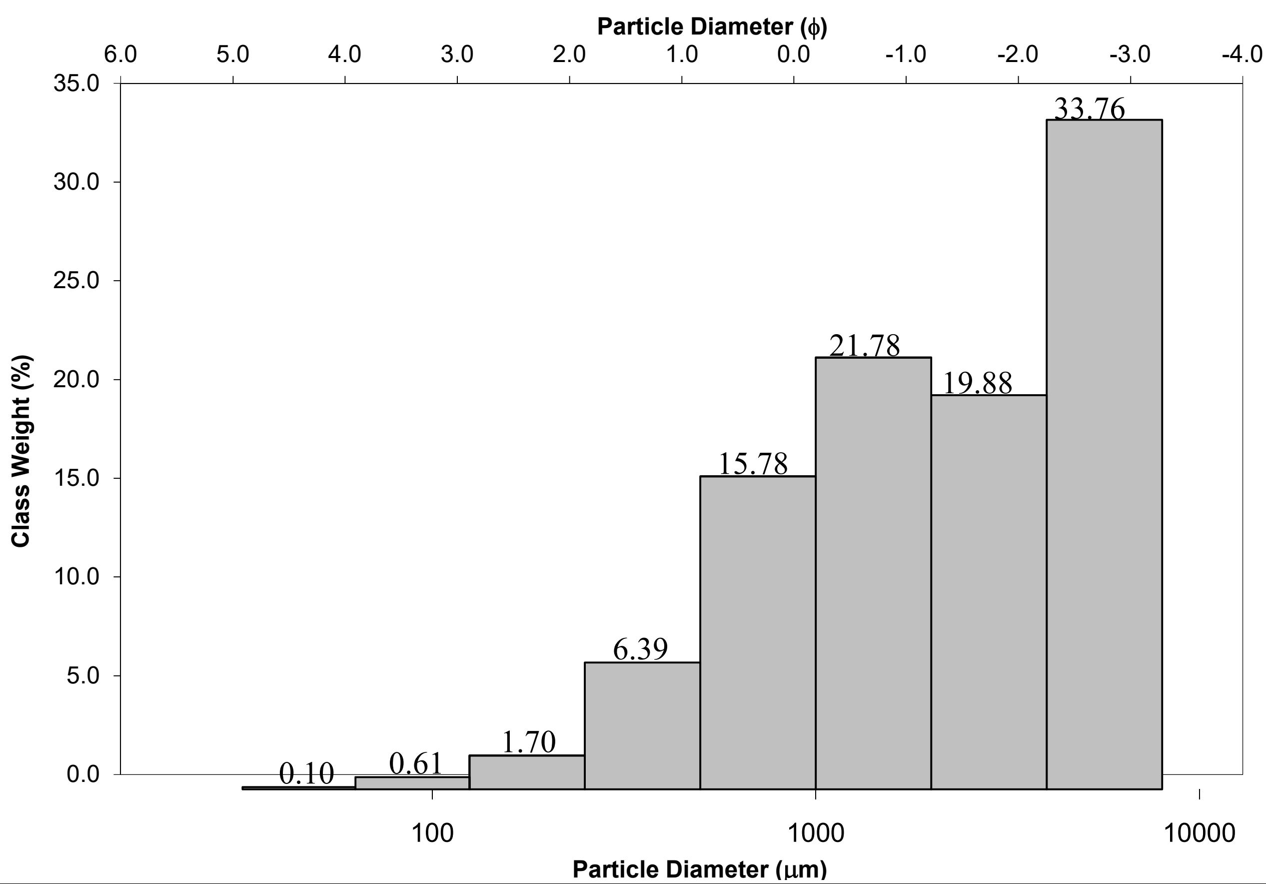
	μm	ϕ
MODE 1:	6000.0	-2.500
MODE 2:	1500.0	-0.500
MODE 3:		
D_{10}:	527.3	-2.704
MEDIAN or D_{50}:	2271.1	-1.183
D_{90}:	6515.4	0.923
(D_{90} / D_{10}):	12.36	-0.342
$(D_{90} - D_{10})$:	5988.1	3.627
(D_{75} / D_{25}):	4.724	0.009
$(D_{75} - D_{25})$:	3775.0	2.240

GRAIN SIZE DISTRIBUTION

GRAVEL:	53.6%	COARSE SAND:	15.8%
SAND:	46.3%	MEDIUM SAND:	6.4%
MUD:	0.1%	FINE SAND:	1.7%
		V FINE SAND:	0.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	33.8%	FINE SILT:	0.0%
V FINE GRAVEL:	19.9%	V FINE SILT:	0.0%
V COARSE SAND:	21.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	3095.2	2011.9	-1.009	2078.3	-1.055	Very Fine Gravel
SORTING (σ):	2225.6	2.651	1.406	2.715	1.441	Poorly Sorted
SKEWNESS (Sk):	0.314	-0.677	0.677	-0.187	0.187	Fine Skewed
KURTOSIS (K):	1.447	2.810	2.810	0.813	0.813	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **810** ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

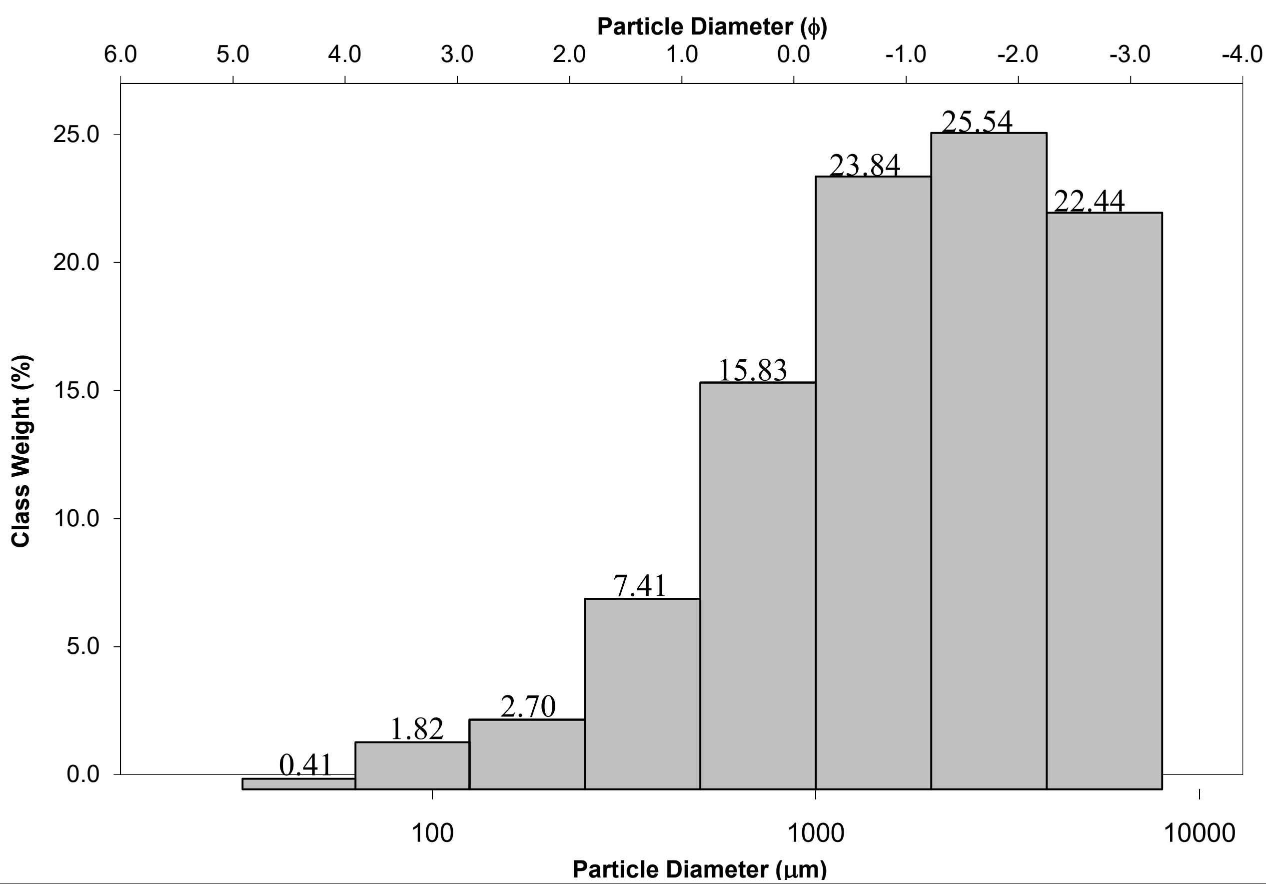
	μm	ϕ
MODE 1:	3000.0	-1.500
MODE 2:		
MODE 3:		
D_{10}:	402.3	-2.554
MEDIAN or D_{50}:	1886.8	-0.916
D_{90}:	5874.5	1.314
(D_{90} / D_{10}):	14.60	-0.514
$(D_{90} - D_{10})$:	5472.2	3.868
(D_{75} / D_{25}):	4.285	-0.105
$(D_{75} - D_{25})$:	2861.2	2.099

GRAIN SIZE DISTRIBUTION

GRAVEL:	48.0%	COARSE SAND:	15.8%
SAND:	51.6%	MEDIUM SAND:	7.4%
MUD:	0.4%	FINE SAND:	2.7%
		V FINE SAND:	1.8%
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:	22.4%	FINE SILT:	0.0%
V FINE GRAVEL:	25.6%	V FINE SILT:	0.0%
V COARSE SAND:	23.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	2624.4	1652.5	-0.725	1755.3	-0.812	Very Coarse Sand
SORTING (σ):	2032.1	2.788	1.479	2.801	1.486	Poorly Sorted
SKEWNESS (Sk):	0.676	-0.791	0.791	-0.161	0.161	Fine Skewed
KURTOSIS (K):	2.067	3.356	3.356	0.930	0.930	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **811**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Fine Gravel

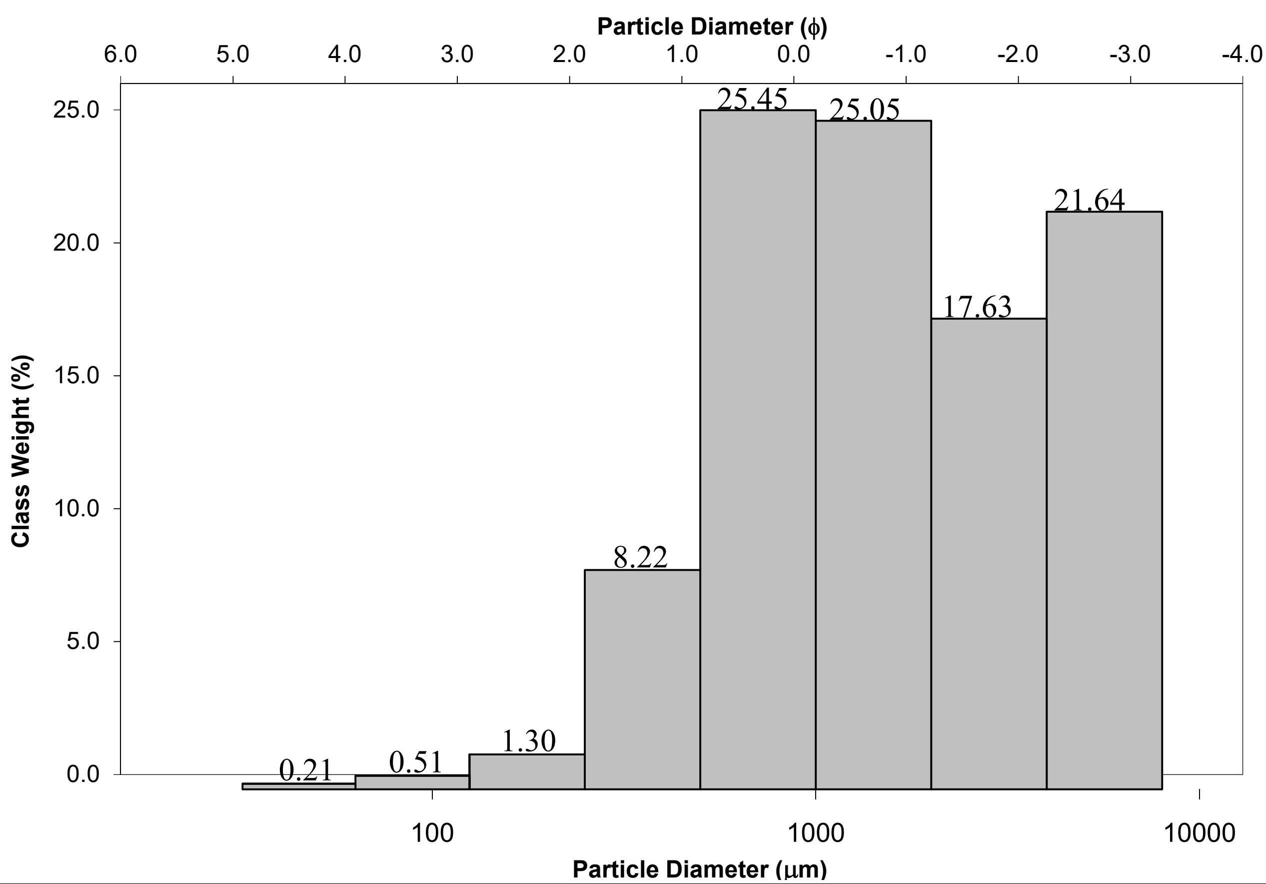
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	490.8	-2.538
MEDIAN or D_{50}:	1486.6	-0.572
D_{90}:	5807.7	1.027
(D_{90} / D_{10}):	11.83	-0.405
(D_{90} - D_{10}):	5316.9	3.565
(D_{75} / D_{25}):	4.688	-0.232
(D_{75} - D_{25}):	2757.8	2.229

GRAIN SIZE DISTRIBUTION

GRAVEL:	39.3%	COARSE SAND:	25.5%
SAND:	60.5%	MEDIUM SAND:	8.2%
MUD:	0.2%	FINE SAND:	1.3%
		V FINE SAND:	0.5%
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:	21.6%	FINE SILT:	0.0%
V FINE GRAVEL:	17.6%	V FINE SILT:	0.0%
V COARSE SAND:	25.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	2428.1	1538.3	-0.621	1609.5	-0.687	Very Coarse Sand
SORTING (σ):	2049.9	2.572	1.363	2.687	1.426	Poorly Sorted
SKEWNESS (Sk):	0.876	-0.237	0.237	0.055	-0.055	Symmetrical
KURTOSIS (K):	2.235	2.579	2.579	0.810	0.810	Platykurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **812**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

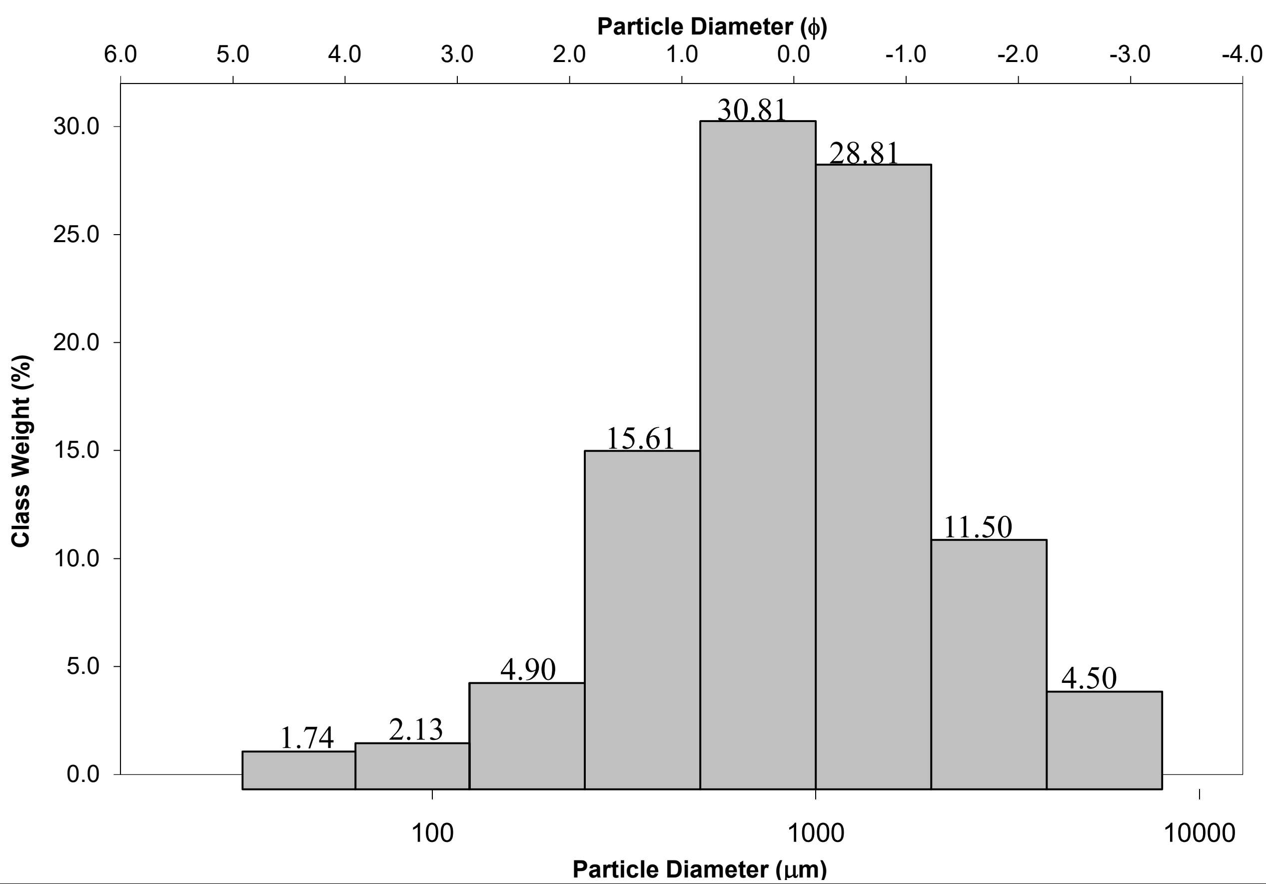
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	264.7	-1.523
MEDIAN or D_{50}:	890.6	0.167
D_{90}:	2873.1	1.917
(D_{90} / D_{10}):	10.85	-1.259
$(D_{90} - D_{10})$:	2608.4	3.440
(D_{75} / D_{25}):	3.174	-1.421
$(D_{75} - D_{25})$:	1103.8	1.666

GRAIN SIZE DISTRIBUTION

GRAVEL:	16.0%	COARSE SAND:	30.8%
SAND:	82.3%	MEDIUM SAND:	15.6%
MUD:	1.7%	FINE SAND:	4.9%
		V FINE SAND:	2.1%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.7%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	4.5%	FINE SILT:	0.0%
V FINE GRAVEL:	11.5%	V FINE SILT:	0.0%
V COARSE SAND:	28.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1349.8	851.9	0.231	850.9	0.233	Coarse Sand
SORTING (σ):	1296.8	2.595	1.375	2.545	1.348	Poorly Sorted
SKEWNESS (Sk):	2.146	-0.501	0.501	-0.088	0.088	Symmetrical
KURTOSIS (K):	7.882	3.700	3.700	1.159	1.159	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **813**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

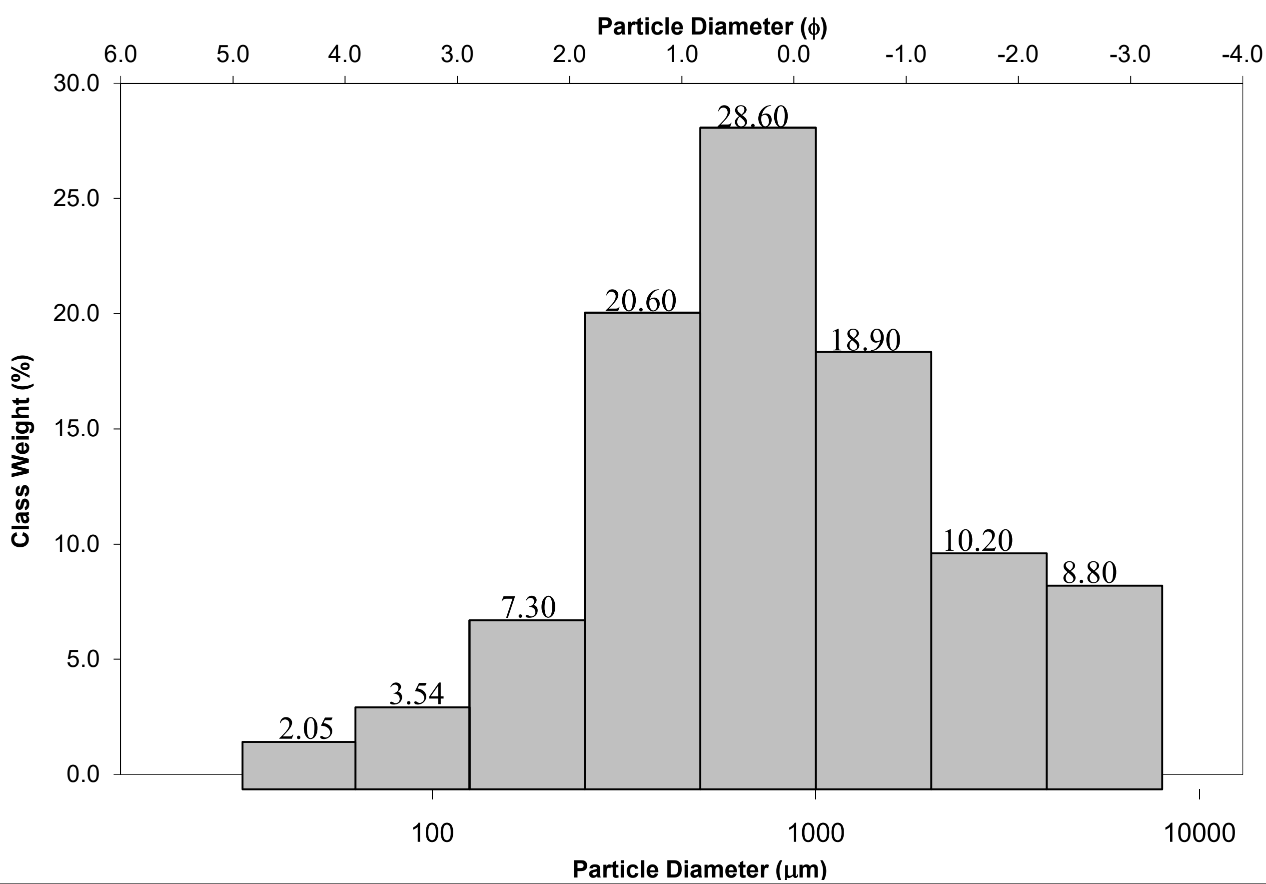
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	191.5	-1.883
MEDIAN or D_{50}:	746.7	0.421
D_{90}:	3689.3	2.385
(D_{90} / D_{10}):	19.27	-1.266
$(D_{90} - D_{10})$:	3497.8	4.268
(D_{75} / D_{25}):	4.266	-2.060
$(D_{75} - D_{25})$:	1229.9	2.093

GRAIN SIZE DISTRIBUTION

GRAVEL:	19.0%	COARSE SAND:	28.6%
SAND:	79.0%	MEDIUM SAND:	20.6%
MUD:	2.0%	FINE SAND:	7.3%
		V FINE SAND:	3.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	8.8%	FINE SILT:	0.0%
V FINE GRAVEL:	10.2%	V FINE SILT:	0.0%
V COARSE SAND:	18.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1428.6	768.9	0.379	799.0	0.324	Coarse Sand
SORTING (σ):	1633.3	2.995	1.583	3.095	1.630	Poorly Sorted
SKEWNESS (Sk):	1.883	-0.130	0.130	0.059	-0.059	Symmetrical
KURTOSIS (K):	5.587	2.898	2.898	1.092	1.092	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **814**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Fine Gravel

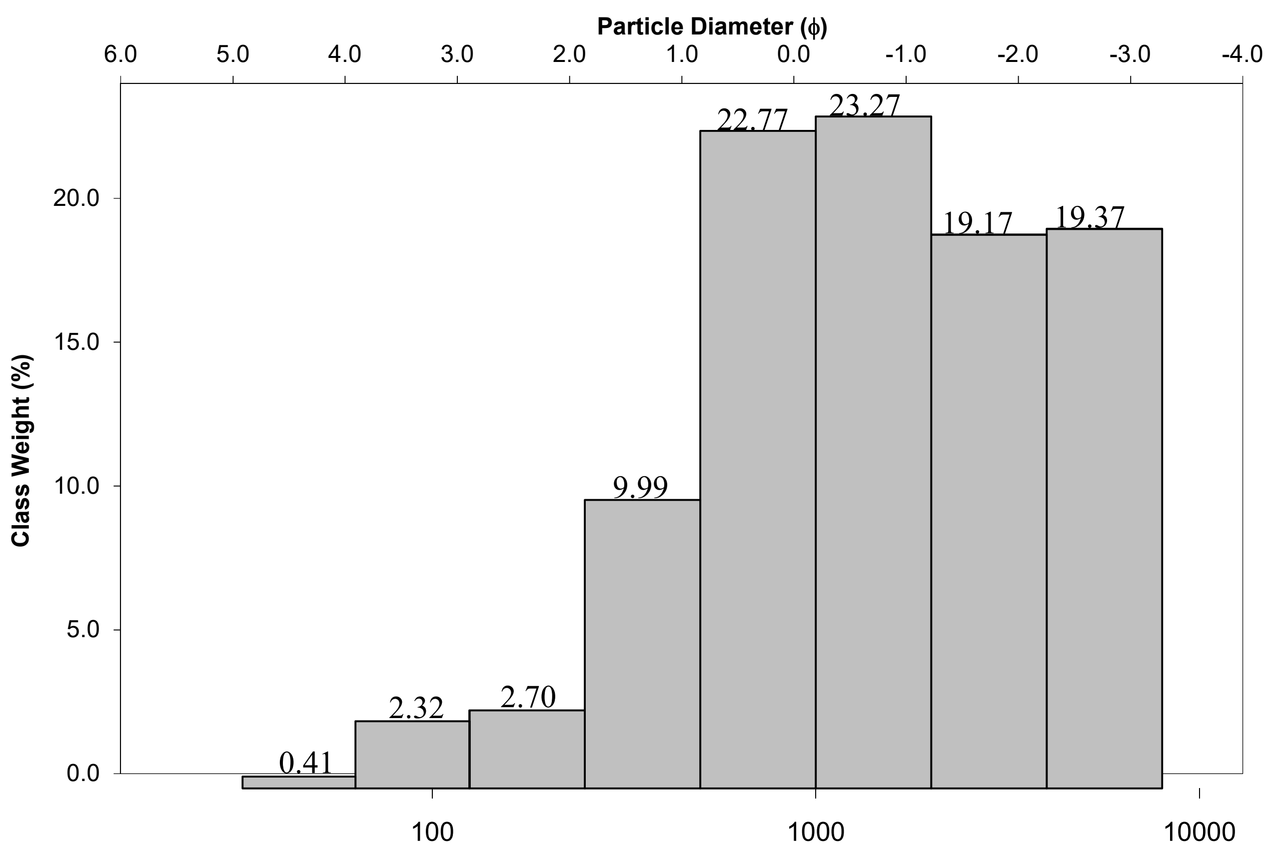
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:	6000.0	-2.500
MODE 3:		
D_{10}:	344.1	-2.484
MEDIAN or D_{50}:	1422.7	-0.509
D_{90}:	5594.5	1.539
(D_{90} / D_{10}):	16.26	-0.620
$(D_{90} - D_{10})$:	5250.4	4.023
(D_{75} / D_{25}):	4.873	-0.339
$(D_{75} - D_{25})$:	2594.9	2.285

GRAIN SIZE DISTRIBUTION

GRAVEL:	38.6%	COARSE SAND:	22.8%
SAND:	61.0%	MEDIUM SAND:	10.0%
MUD:	0.4%	FINE SAND:	2.7%
		V FINE SAND:	2.3%
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:	19.4%	FINE SILT:	0.0%
V FINE GRAVEL:	19.2%	V FINE SILT:	0.0%
V COARSE SAND:	23.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	2303.1	1374.8	-0.459	1484.5	-0.570	Very Coarse Sand
SORTING (σ):	2016.4	2.862	1.517	2.883	1.528	Poorly Sorted
SKEWNESS (Sk):	0.929	-0.484	0.484	-0.014	0.014	Symmetrical
KURTOSIS (K):	2.434	2.891	2.891	0.877	0.877	Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **815** ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

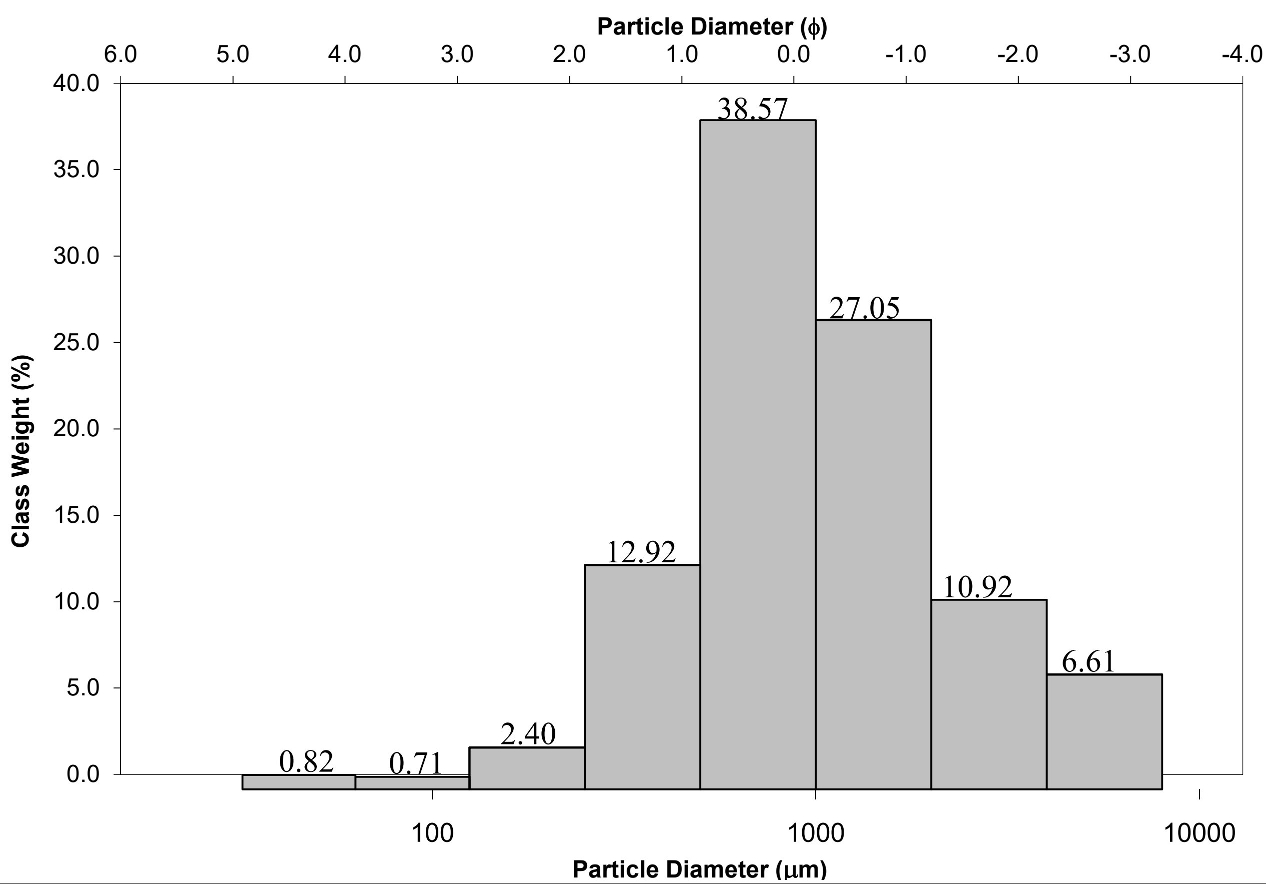
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	346.6	-1.690
MEDIAN or D_{50}:	907.4	0.140
D_{90}:	3226.4	1.529
(D_{90} / D_{10}):	9.309	-0.905
$(D_{90} - D_{10})$:	2879.8	3.219
(D_{75} / D_{25}):	2.853	-1.089
$(D_{75} - D_{25})$:	1072.8	1.512

GRAIN SIZE DISTRIBUTION

GRAVEL:	17.5%	COARSE SAND:	38.6%
SAND:	81.7%	MEDIUM SAND:	12.9%
MUD:	0.8%	FINE SAND:	2.4%
		V FINE SAND:	0.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	6.6%	FINE SILT:	0.0%
V FINE GRAVEL:	10.9%	V FINE SILT:	0.0%
V COARSE SAND:	27.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1473.6	970.7	0.043	985.3	0.021	Coarse Sand
SORTING (σ):	1427.2	2.343	1.228	2.268	1.181	Poorly Sorted
SKEWNESS (Sk):	2.102	-0.134	0.134	0.154	-0.154	Coarse Skewed
KURTOSIS (K):	6.934	3.944	3.944	1.127	1.127	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **816**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

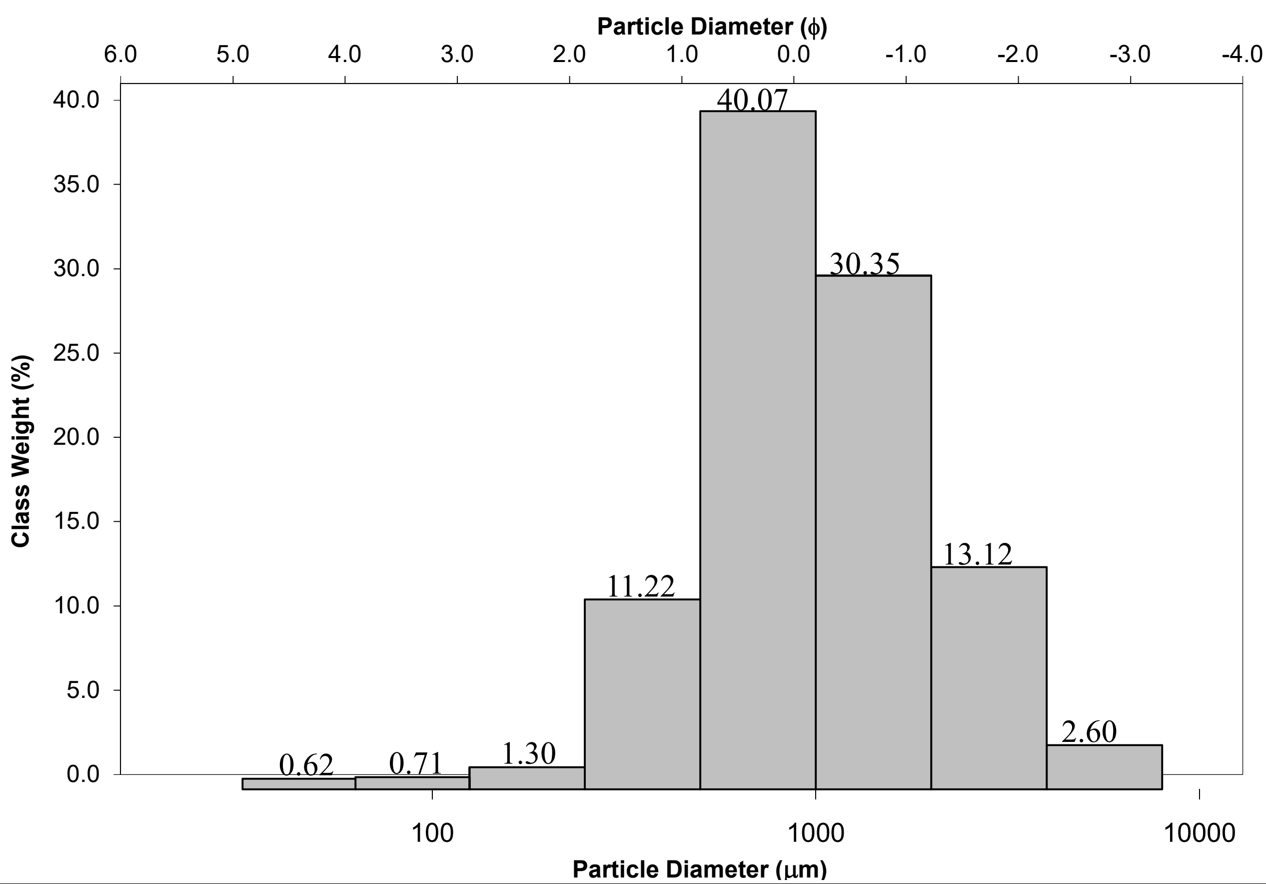
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	394.7	-1.437
MEDIAN or D_{50}:	934.7	0.097
D_{90}:	2706.9	1.341
(D_{90} / D_{10}):	6.858	-0.933
$(D_{90} - D_{10})$:	2312.2	2.778
(D_{75} / D_{25}):	2.668	-1.038
$(D_{75} - D_{25})$:	1012.0	1.416

GRAIN SIZE DISTRIBUTION

GRAVEL:	15.7%	COARSE SAND:	40.1%
SAND:	83.7%	MEDIUM SAND:	11.2%
MUD:	0.6%	FINE SAND:	1.3%
		V FINE SAND:	0.7%
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:	2.6%	FINE SILT:	0.0%
V FINE GRAVEL:	13.1%	V FINE SILT:	0.0%
V COARSE SAND:	30.4%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1351.6	973.4	0.039	988.0	0.017	Coarse Sand
SORTING (σ):	1103.3	2.118	1.083	2.042	1.030	Poorly Sorted
SKEWNESS (Sk):	2.208	-0.351	0.351	0.093	-0.093	Symmetrical
KURTOSIS (K):	9.006	4.496	4.496	1.043	1.043	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **817**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

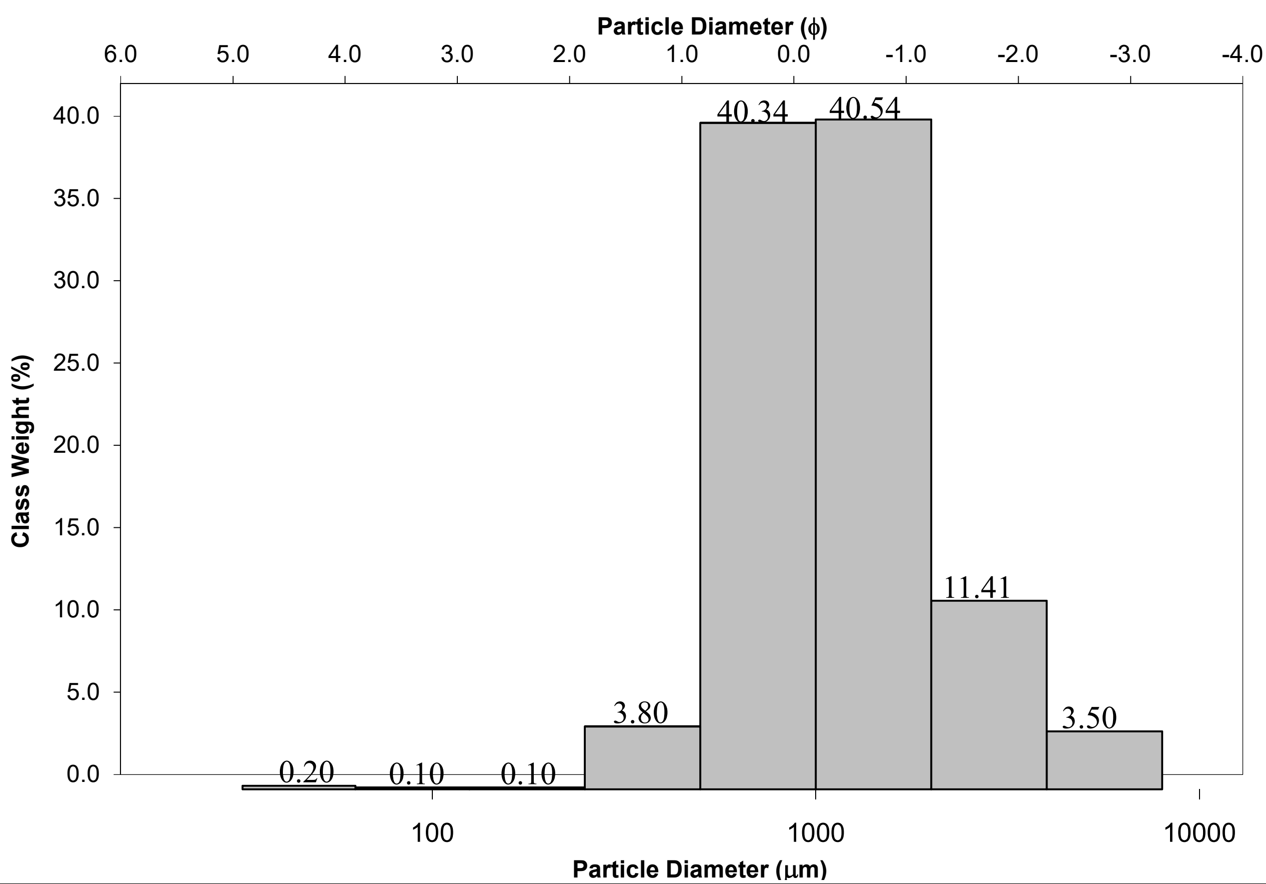
	μm	ϕ
MODE 1:	1500.0	-0.500
MODE 2:		
MODE 3:		
D_{10}:	552.4	-1.431
MEDIAN or D_{50}:	1097.8	-0.135
D_{90}:	2695.8	0.856
(D_{90} / D_{10}):	4.881	-0.599
$(D_{90} - D_{10})$:	2143.4	2.287
(D_{75} / D_{25}):	2.355	-0.645
$(D_{75} - D_{25})$:	968.5	1.236

GRAIN SIZE DISTRIBUTION

GRAVEL:	14.9%	COARSE SAND:	40.3%
SAND:	84.9%	MEDIUM SAND:	3.8%
MUD:	0.2%	FINE SAND:	0.1%
		V FINE SAND:	0.1%
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:	3.5%	FINE SILT:	0.0%
V FINE GRAVEL:	11.4%	V FINE SILT:	0.0%
V COARSE SAND:	40.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1477.9	1139.0	-0.188	1096.9	-0.133	Very Coarse Sand
SORTING (σ):	1117.5	1.849	0.887	1.805	0.852	Moderately Sorted
SKEWNESS (Sk):	2.455	0.167	-0.167	0.108	-0.108	Coarse Skewed
KURTOSIS (K):	9.907	4.727	4.727	0.945	0.945	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **1110**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

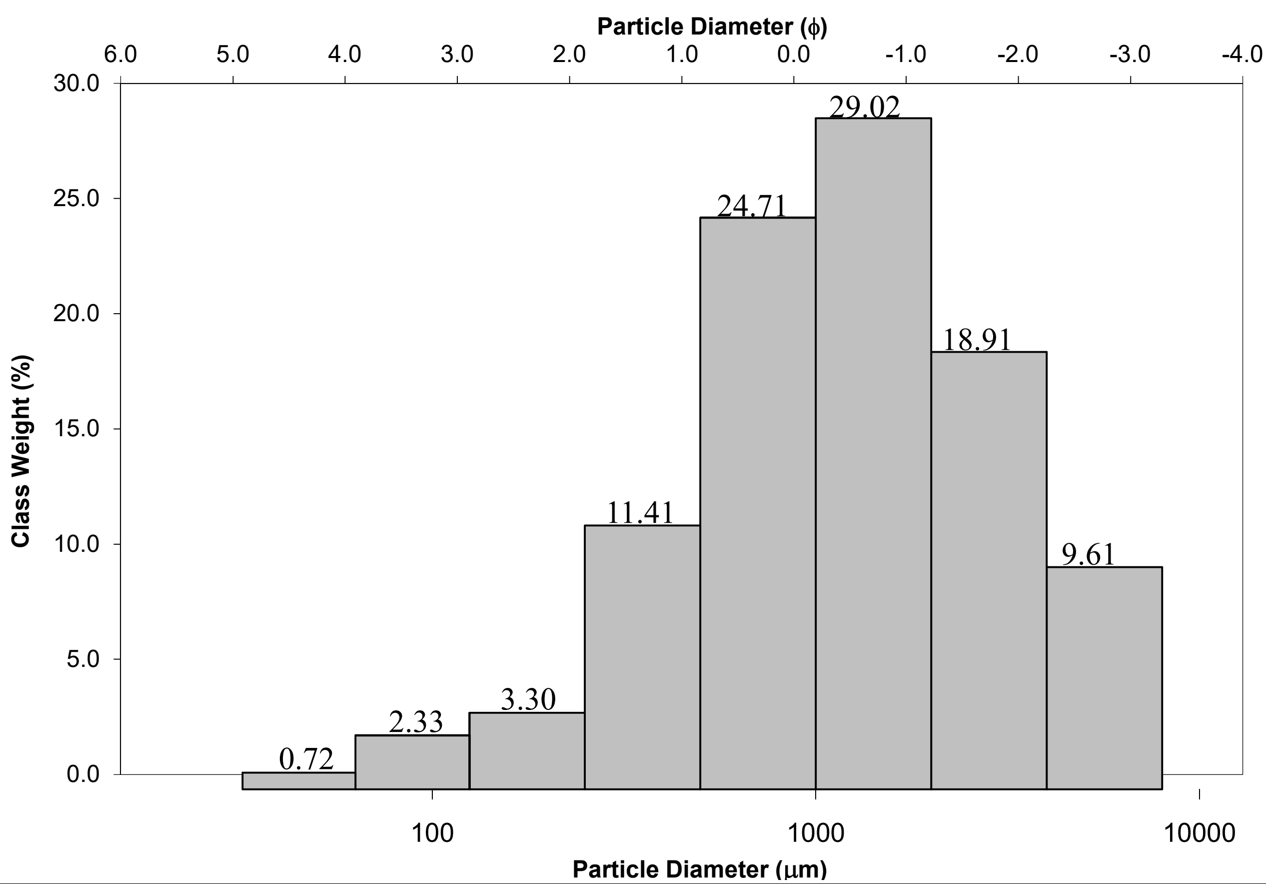
	μm	φ
MODE 1:	1500.0	-0.500
MODE 2:		
MODE 3:		
D_{10}:	312.9	-1.979
MEDIAN or D_{50}:	1197.8	-0.260
D_{90}:	3943.2	1.676
(D_{90} / D_{10}):	12.60	-0.847
$(D_{90} - D_{10})$:	3630.3	3.656
(D_{75} / D_{25}):	3.711	-0.595
$(D_{75} - D_{25})$:	1662.8	1.892

GRAIN SIZE DISTRIBUTION

GRAVEL:	28.5%	COARSE SAND:	24.7%
SAND:	70.8%	MEDIUM SAND:	11.4%
MUD:	0.7%	FINE SAND:	3.3%
		V FINE SAND:	2.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.7%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	9.6%	FINE SILT:	0.0%
V FINE GRAVEL:	18.9%	V FINE SILT:	0.0%
V COARSE SAND:	29.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1816.5	1132.9	-0.180	1195.3	-0.257	Very Coarse Sand
SORTING (σ):	1634.7	2.674	1.419	2.717	1.442	Poorly Sorted
SKEWNESS (Sk):	1.465	-0.511	0.511	-0.046	0.046	Symmetrical
KURTOSIS (K):	4.359	3.336	3.336	1.056	1.056	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **1111**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

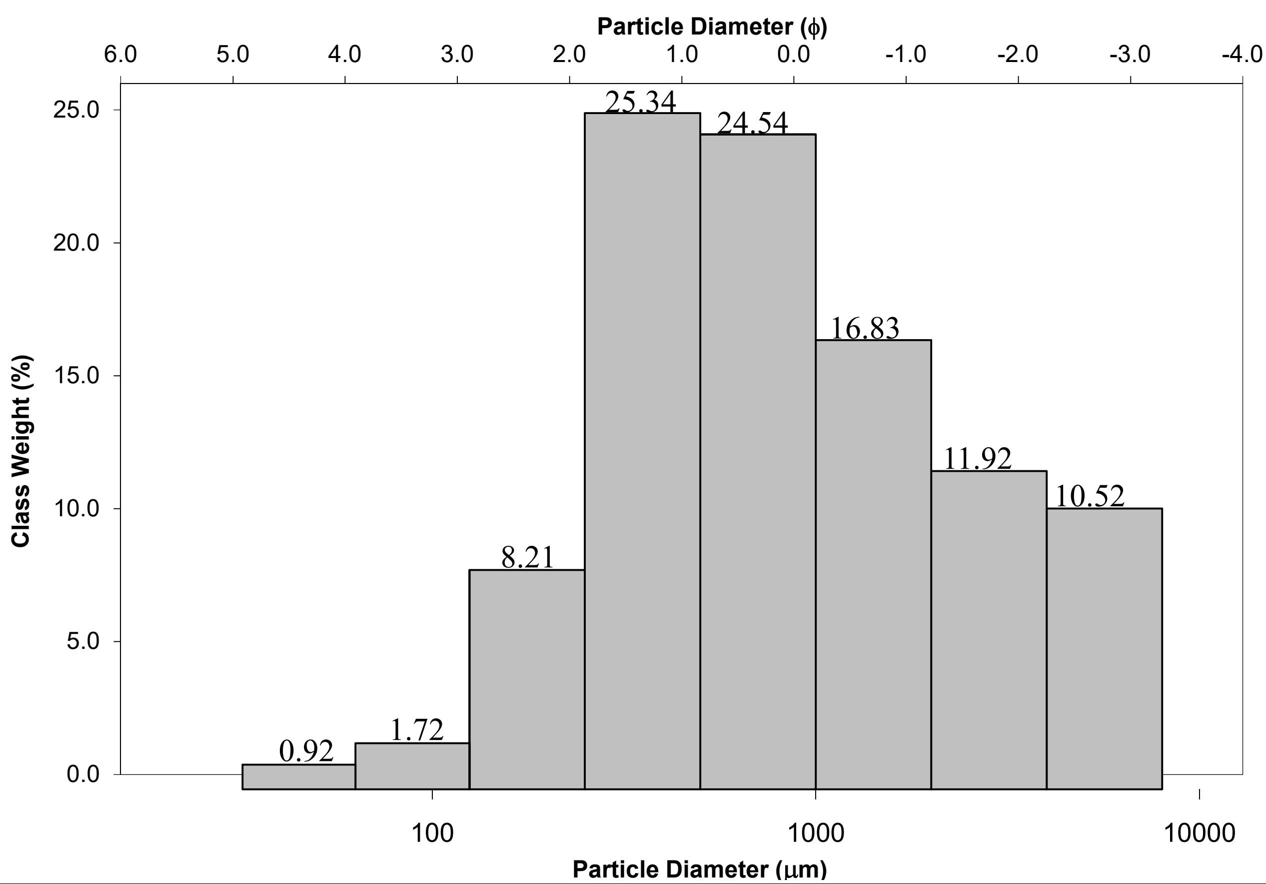
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	233.3	-2.050
MEDIAN or D_{50}:	738.8	0.437
D_{90}:	4139.7	2.100
(D_{90} / D_{10}):	17.75	-1.025
(D_{90} - D_{10}):	3906.4	4.150
(D_{75} / D_{25}):	4.887	-1.699
(D_{75} - D_{25}):	1431.9	2.289

GRAIN SIZE DISTRIBUTION

GRAVEL:	22.4%	COARSE SAND:	24.5%
SAND:	76.7%	MEDIUM SAND:	25.4%
MUD:	0.9%	FINE SAND:	8.2%
		V FINE SAND:	1.7%
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:	10.5%	FINE SILT:	0.0%
V FINE GRAVEL:	11.9%	V FINE SILT:	0.0%
V COARSE SAND:	16.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1538.1	822.3	0.282	852.2	0.231	Coarse Sand
SORTING (σ):	1746.6	2.941	1.556	3.089	1.627	Poorly Sorted
SKEWNESS (Sk):	1.673	0.115	-0.115	0.159	-0.159	Coarse Skewed
KURTOSIS (K):	4.642	2.509	2.509	0.937	0.937	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **1112**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

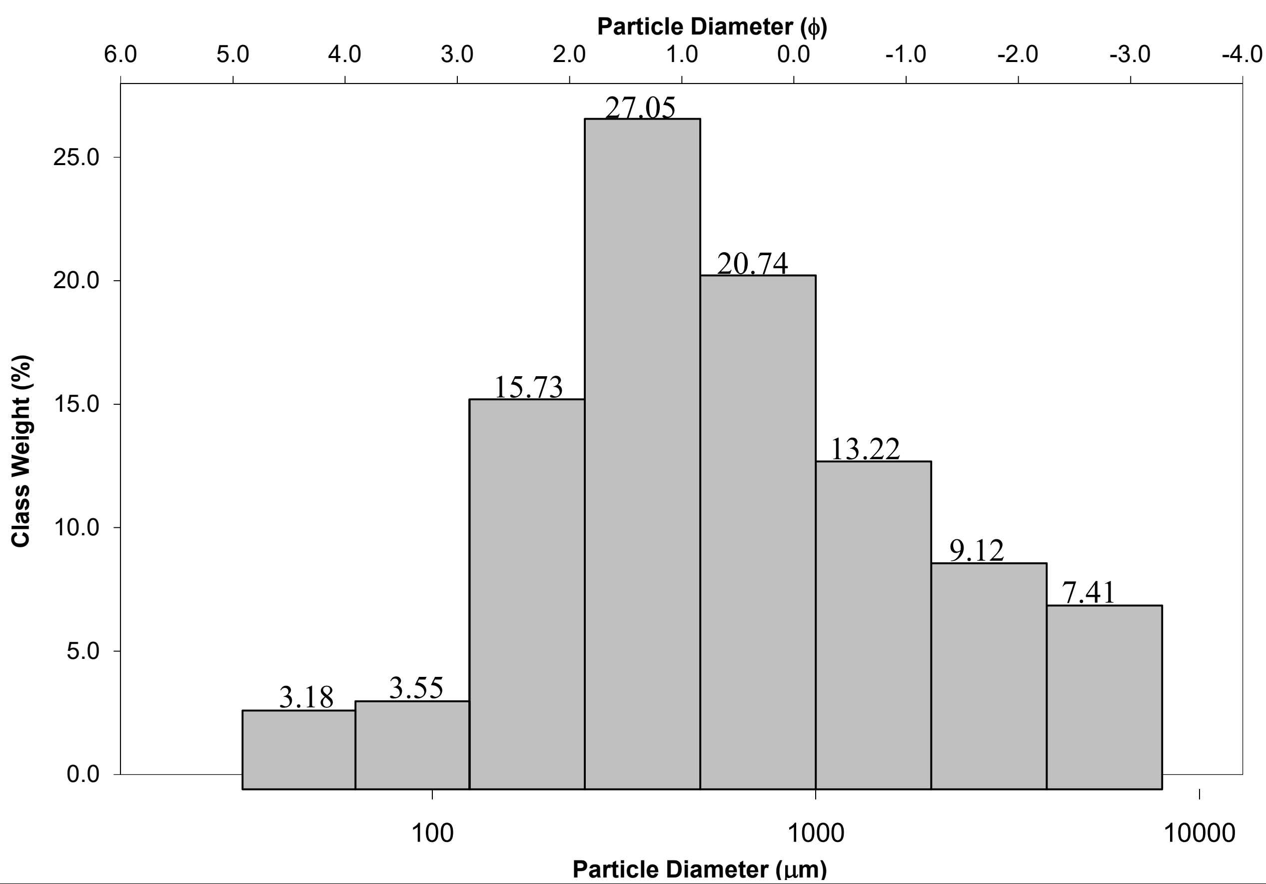
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	145.1	-1.718
MEDIAN or D_{50}:	509.3	0.973
D_{90}:	3288.8	2.785
(D_{90} / D_{10}):	22.67	-1.622
$(D_{90} - D_{10})$:	3143.8	4.503
(D_{75} / D_{25}):	4.805	-5.260
$(D_{75} - D_{25})$:	1017.5	2.265

GRAIN SIZE DISTRIBUTION

GRAVEL:	16.5%	COARSE SAND:	20.8%
SAND:	80.4%	MEDIUM SAND:	27.1%
MUD:	3.1%	FINE SAND:	15.7%
		V FINE SAND:	3.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	7.4%	FINE SILT:	0.0%
V FINE GRAVEL:	9.1%	V FINE SILT:	0.0%
V COARSE SAND:	13.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1209.3	583.6	0.777	585.4	0.773	Coarse Sand
SORTING (σ):	1577.9	3.187	1.672	3.346	1.742	Poorly Sorted
SKEWNESS (Sk):	2.099	0.167	-0.167	0.158	-0.158	Coarse Skewed
KURTOSIS (K):	6.527	2.631	2.631	1.047	1.047	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **1211** ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

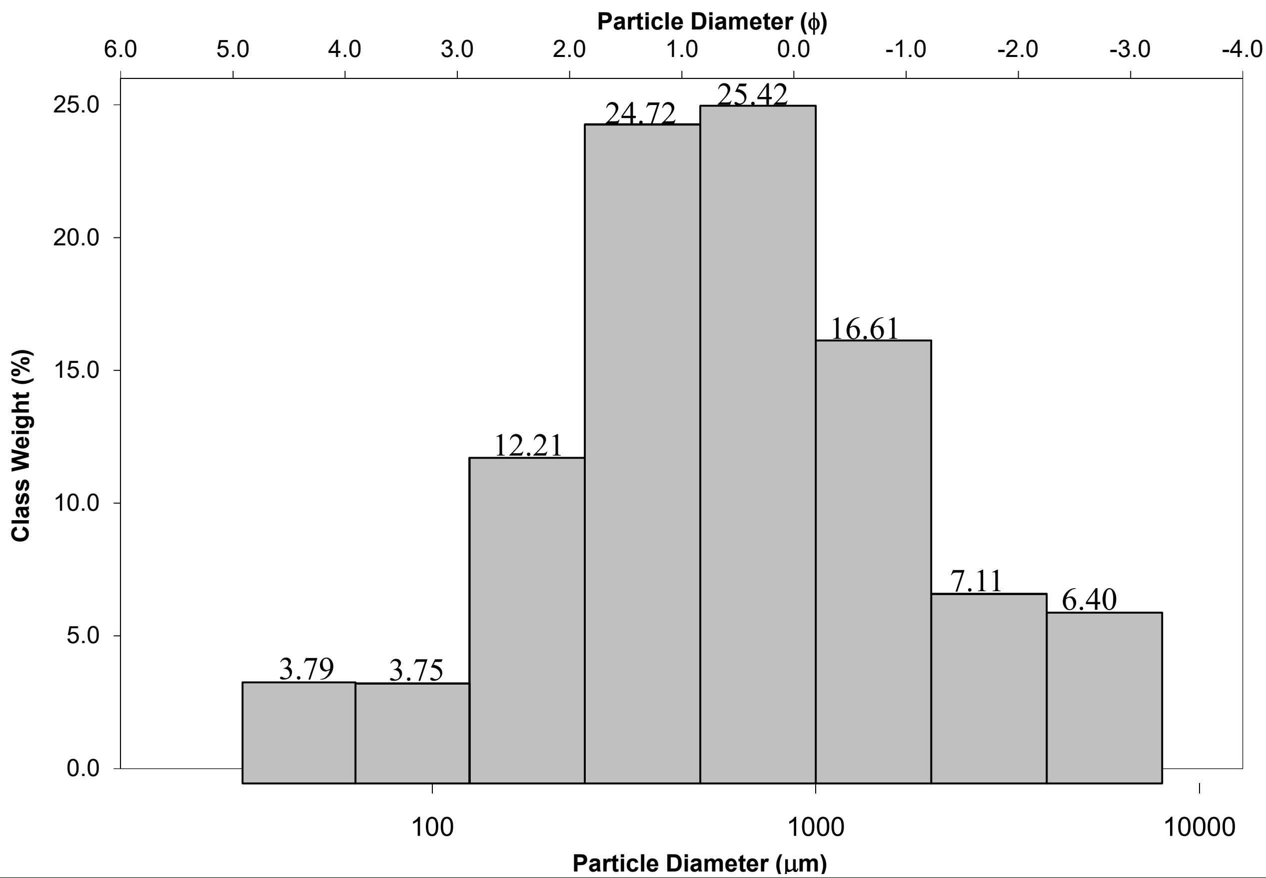
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	144.7	-1.496
MEDIAN or D_{50}:	582.6	0.780
D_{90}:	2820.2	2.789
(D_{90} / D_{10}):	19.49	-1.864
$(D_{90} - D_{10})$:	2675.4	4.284
(D_{75} / D_{25}):	4.268	-5.748
$(D_{75} - D_{25})$:	949.4	2.094

GRAIN SIZE DISTRIBUTION

GRAVEL:	13.5%	COARSE SAND:	25.5%
SAND:	82.8%	MEDIUM SAND:	24.7%
MUD:	3.7%	FINE SAND:	12.2%
		V FINE SAND:	3.8%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.7%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	6.4%	FINE SILT:	0.0%
V FINE GRAVEL:	7.1%	V FINE SILT:	0.0%
V COARSE SAND:	16.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1159.6	594.8	0.749	597.9	0.742	Coarse Sand
SORTING (σ):	1470.1	3.072	1.619	3.195	1.676	Poorly Sorted
SKEWNESS (Sk):	2.322	-0.026	0.026	0.029	-0.029	Symmetrical
KURTOSIS (K):	7.779	2.892	2.892	1.148	1.148	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **MS BA Center**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

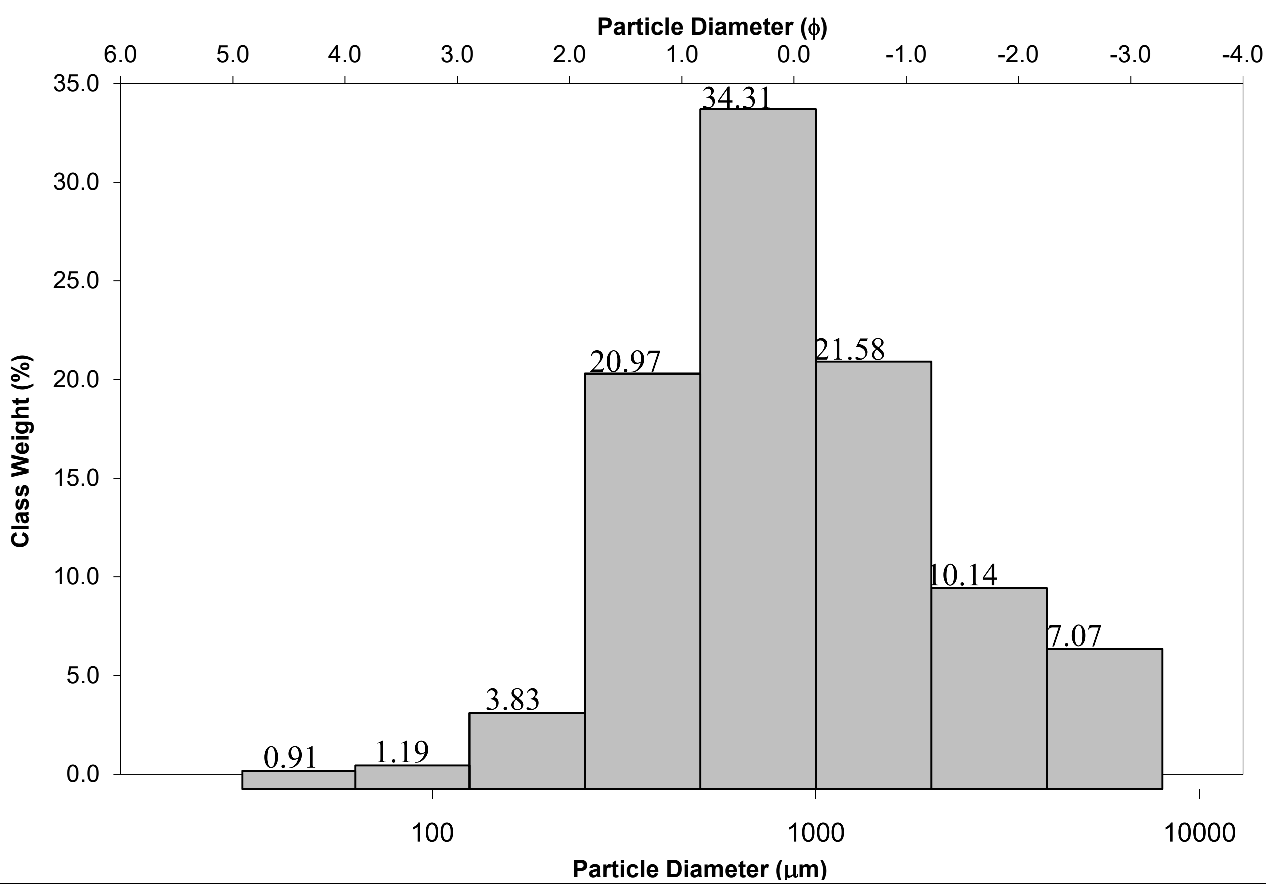
	μm	φ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	286.3	-1.711
MEDIAN or D_{50}:	797.6	0.326
D_{90}:	3274.7	1.804
(D_{90} / D_{10}):	11.44	-1.054
$(D_{90} - D_{10})$:	2988.4	3.516
(D_{75} / D_{25}):	3.314	-1.704
$(D_{75} - D_{25})$:	1087.7	1.729

GRAIN SIZE DISTRIBUTION

GRAVEL:	17.2%	COARSE SAND:	34.3%
SAND:	81.9%	MEDIUM SAND:	21.0%
MUD:	0.9%	FINE SAND:	3.8%
		V FINE SAND:	1.2%
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:	7.1%	FINE SILT:	0.0%
V FINE GRAVEL:	10.1%	V FINE SILT:	0.0%
V COARSE SAND:	21.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	1397.2	854.9	0.226	845.8	0.242	Coarse Sand
SORTING (σ):	1488.7	2.529	1.339	2.541	1.346	Poorly Sorted
SKEWNESS (Sk):	2.085	0.021	-0.021	0.127	-0.127	Coarse Skewed
KURTOSIS (K):	6.686	3.329	3.329	1.073	1.073	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **MS BA North**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Medium Sand

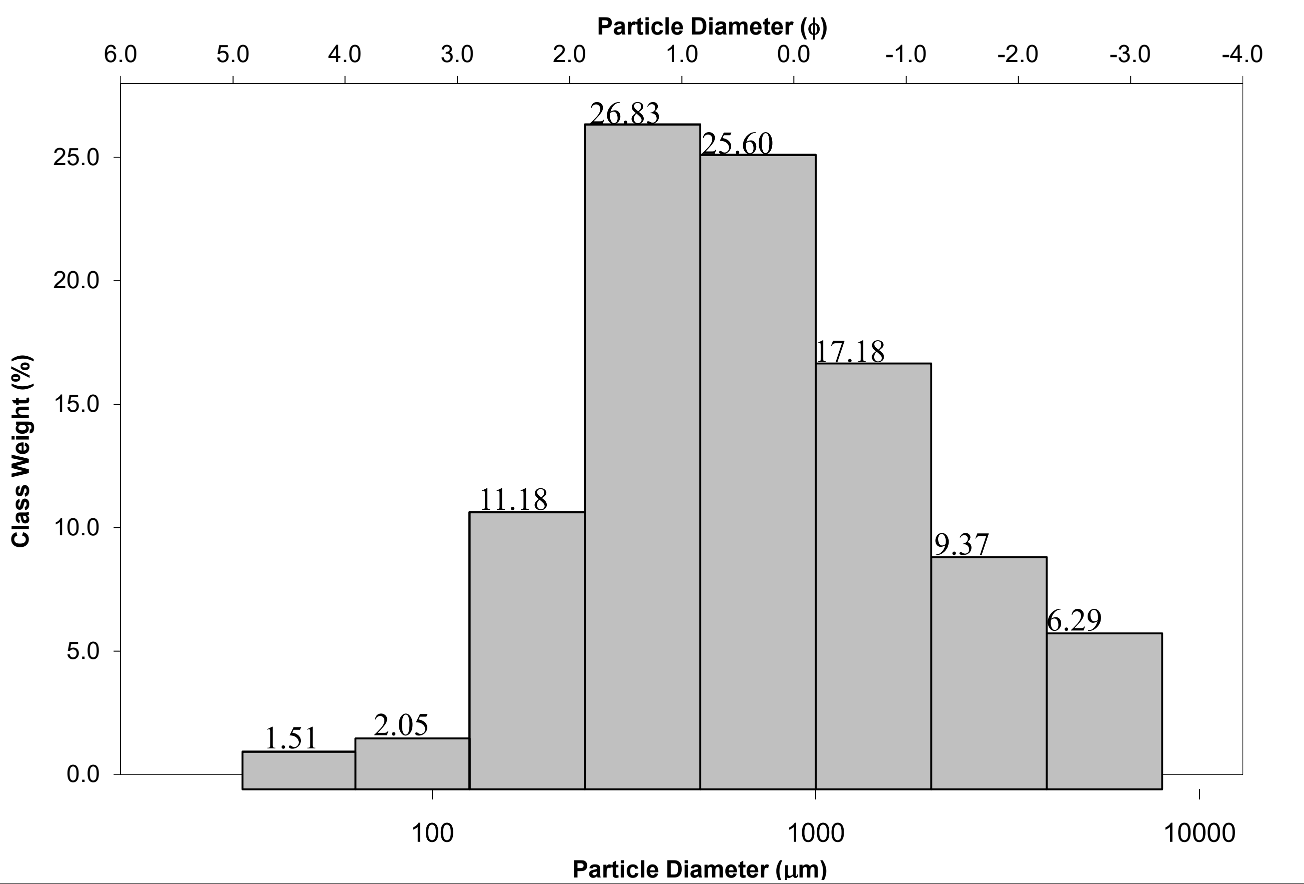
	μm	ϕ
MODE 1:	375.0	1.500
MODE 2:		
MODE 3:		
D_{10}:	187.0	-1.605
MEDIAN or D_{50}:	628.8	0.669
D_{90}:	3040.9	2.419
(D_{90} / D_{10}):	16.27	-1.508
$(D_{90} - D_{10})$:	2854.0	4.024
(D_{75} / D_{25}):	4.207	-3.536
$(D_{75} - D_{25})$:	1046.4	2.073

GRAIN SIZE DISTRIBUTION

GRAVEL:	15.7%	COARSE SAND:	25.6%
SAND:	82.9%	MEDIUM SAND:	26.8%
MUD:	1.5%	FINE SAND:	11.2%
		V FINE SAND:	2.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.5%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	6.3%	FINE SILT:	0.0%
V FINE GRAVEL:	9.4%	V FINE SILT:	0.0%
V COARSE SAND:	17.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1232.9	676.7	0.563	684.6	0.547	Coarse Sand
SORTING (σ):	1470.2	2.822	1.497	2.831	1.501	Poorly Sorted
SKEWNESS (Sk):	2.189	0.122	-0.122	0.130	-0.130	Coarse Skewed
KURTOSIS (K):	7.227	2.830	2.830	1.003	1.003	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **MS BA South**

ANALYST & DATE: GAMMA, 6/10/2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Sand

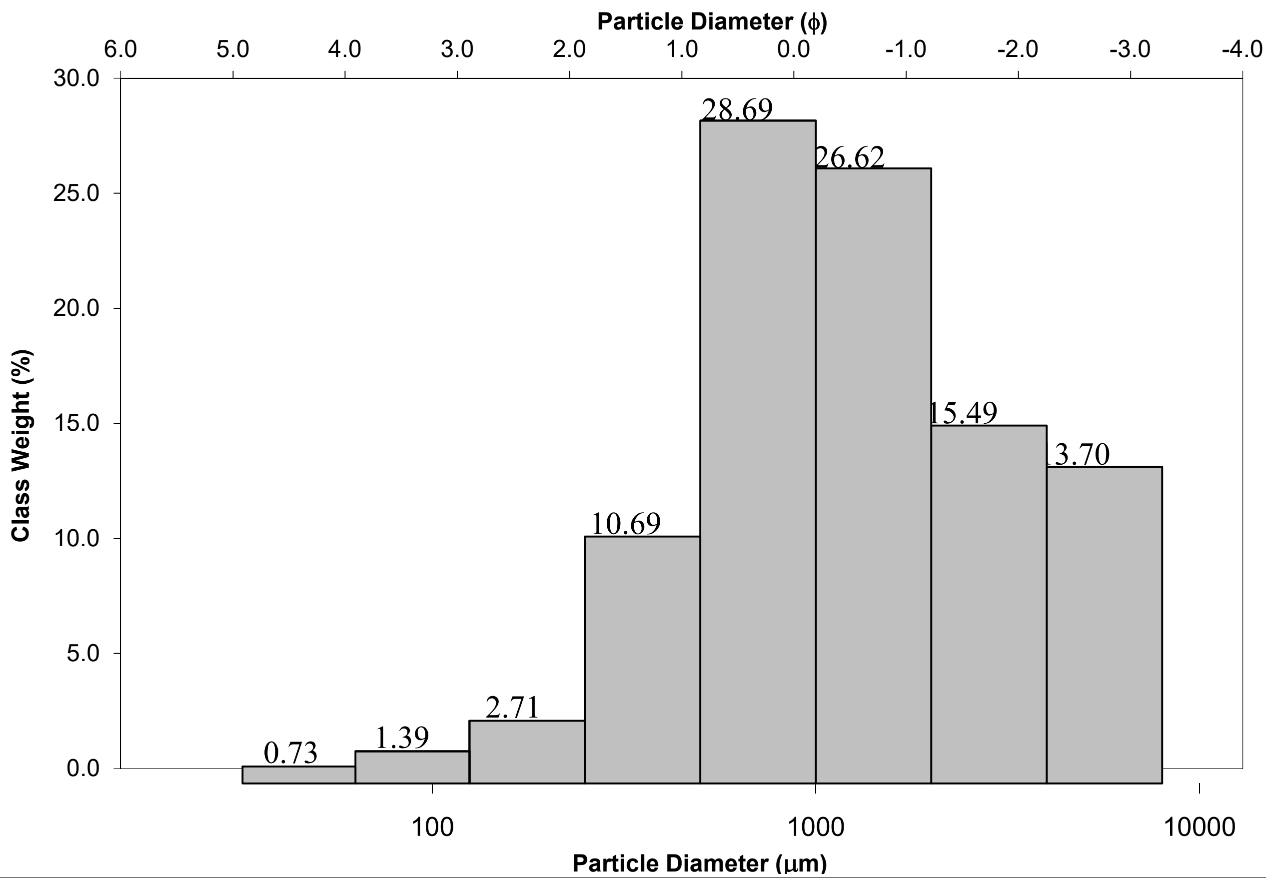
	μm	ϕ
MODE 1:	750.0	0.500
MODE 2:		
MODE 3:		
D_{10}:	350.4	-2.270
MEDIAN or D_{50}:	1163.6	-0.219
D_{90}:	4823.9	1.513
(D_{90} / D_{10}):	13.77	-0.666
$(D_{90} - D_{10})$:	4473.5	3.783
(D_{75} / D_{25}):	3.835	-0.526
$(D_{75} - D_{25})$:	1783.8	1.939

GRAIN SIZE DISTRIBUTION

GRAVEL:	29.2%	COARSE SAND:	28.7%
SAND:	70.1%	MEDIUM SAND:	10.7%
MUD:	0.7%	FINE SAND:	2.7%
		V FINE SAND:	1.4%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.7%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	13.7%	FINE SILT:	0.0%
V FINE GRAVEL:	15.5%	V FINE SILT:	0.0%
V COARSE SAND:	26.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1948.3	1194.8	-0.257	1285.9	-0.363	Very Coarse Sand
SORTING (σ):	1818.8	2.663	1.413	2.653	1.408	Poorly Sorted
SKEWNESS (Sk):	1.342	-0.319	0.319	0.100	-0.100	Symmetrical
KURTOSIS (K):	3.554	3.209	3.209	0.976	0.976	Mesokurtic

GRAIN SIZE DISTRIBUTION



ANEXO III

Results of Numeric Simulations

OLUCA-SP and COPLA-SP models

Wave Height and Intensity of Coastal Currents

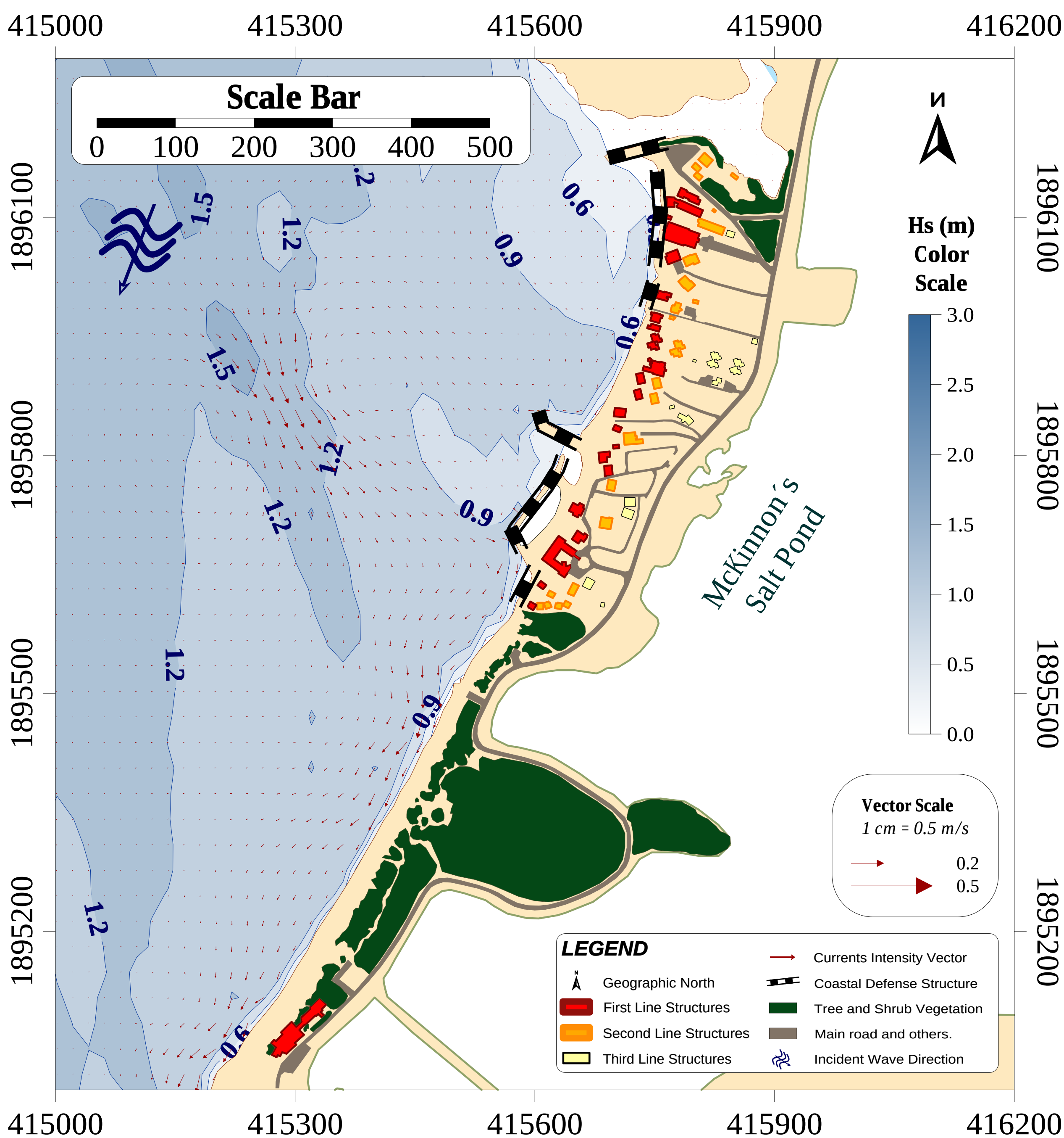
Project: Runaway Bay Beach. Antigua.

Graphic: Wave Height Color Scale + Vectors of Currents

Mean Regime
Course: NNE
Hs = 1.91 m
Pp = 8.78 s

Software Developed by

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 1.91 m* *h: 10 m* *fp: 0.11 Hz* *g: 3.3* *Nº Comp.: 16* ***Directional Spectrum*** *qm : -40° (N22.5E)* *s: 16° - Nº Comp.: 15*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 10 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

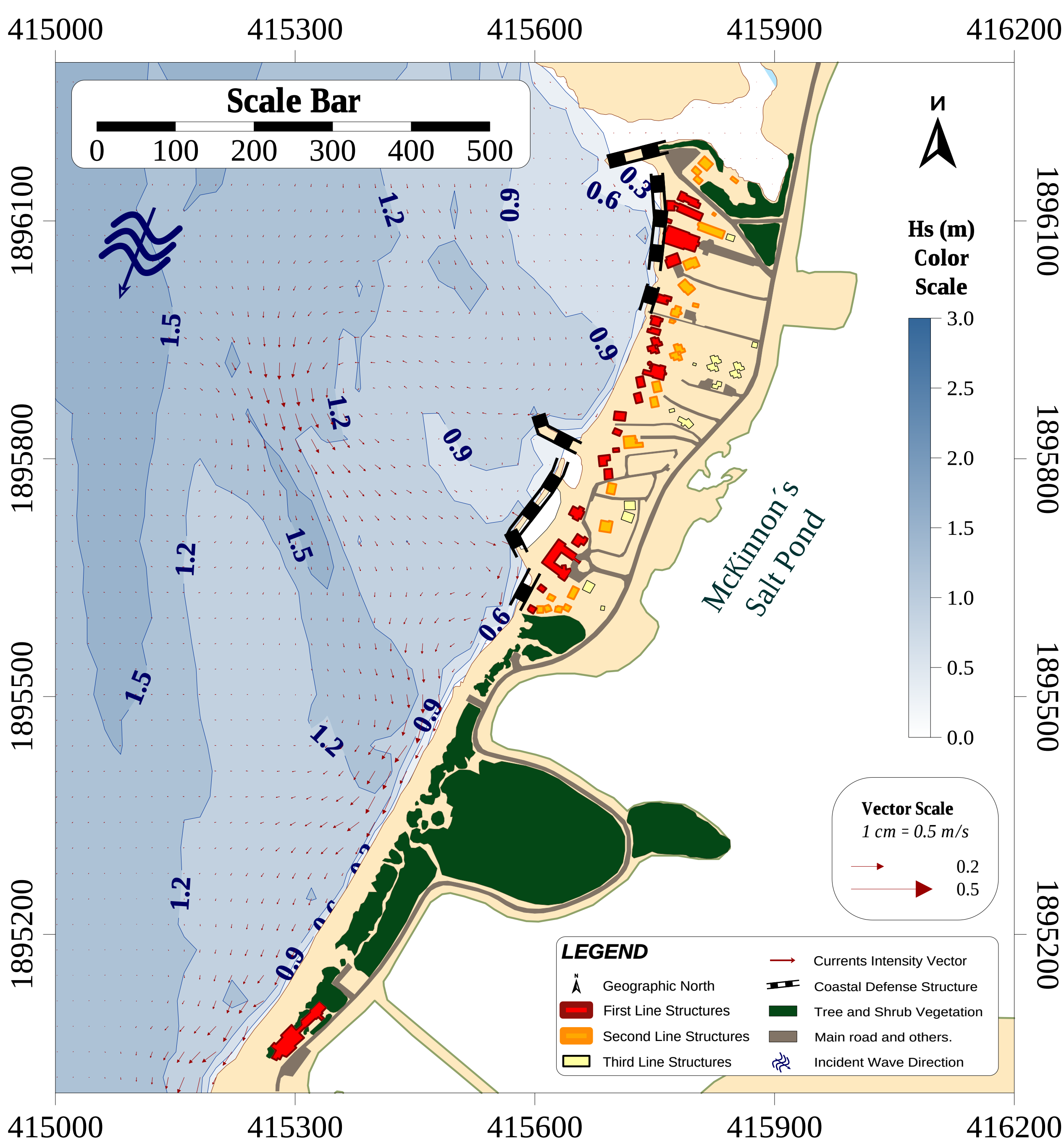
Project: Runaway Bay Beach. Antigua.

Graphic: Wave Height Color Scale + Vectors of Currents

Event of the Year
Course: NNE
Hs = 4.48 m
Pp = 8.78 s

Software Developed by
MINISTERIO DE MEDIO AMBIENTE
GIOC

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 4.48 m* *h: 10 m* *fp: 0.11 Hz* *g: 3.3* *Nº Comp.: 12* ***Directional Spectrum*** *qm : -40° (N22.5E)* *s: 12° - Nº Comp.: 11*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 10 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

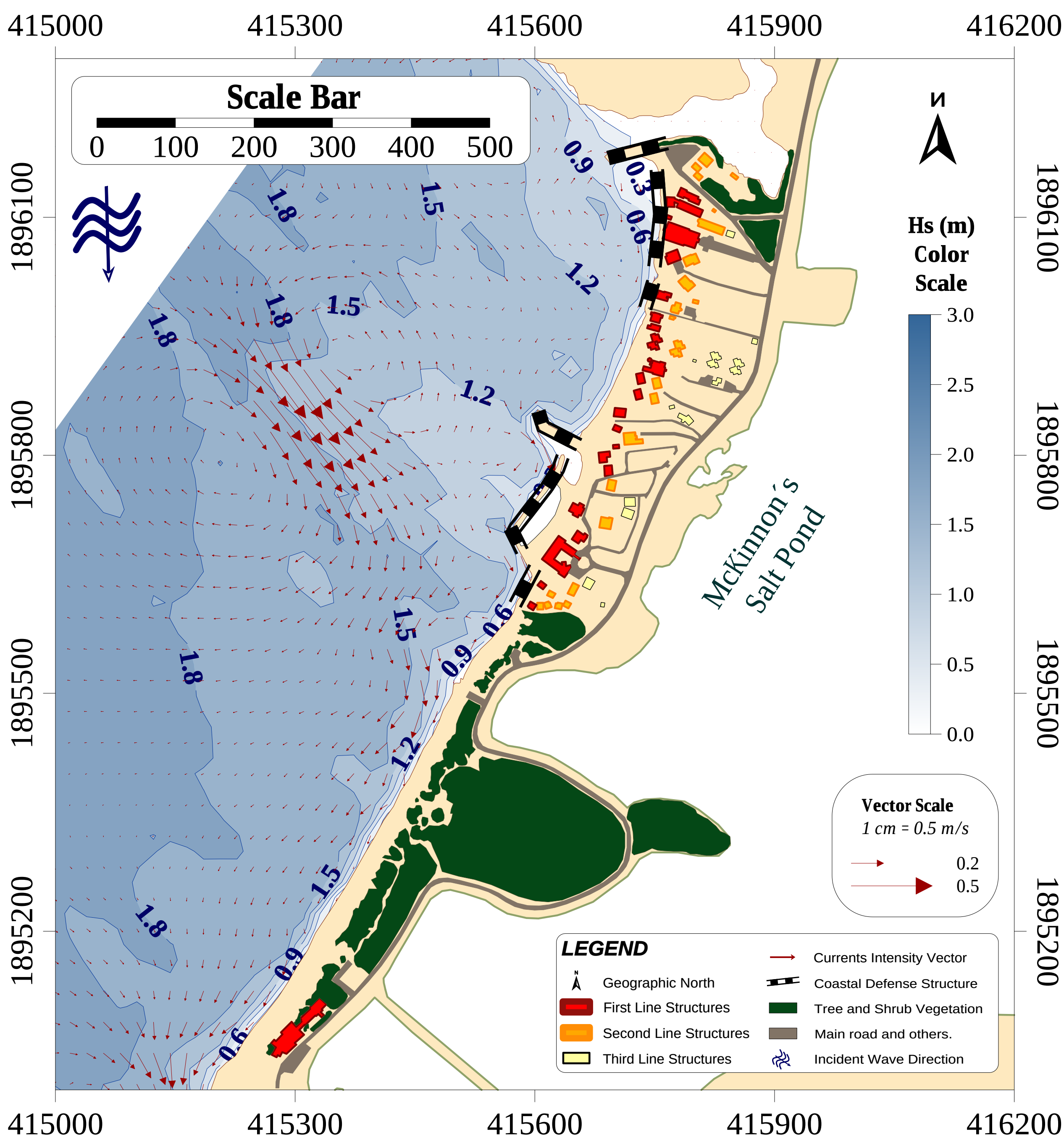
Graphic: Wave Height Color Scale + Vectors of Currents

TC RP 10 Years
Course: North
Hs = 5.71 m
Pp = 9.93 s

Software Developed by

MINISTERIO DE MEDIO AMBIENTE · GIOC

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 5.71 m* *h: 10 m* *fp: 0.11 Hz* *g: 3.3* *Nº Comp.: 12* ***Directional Spectrum*** *qm : -27.5° (N)* *s: 12° - Nº Comp.: 11*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

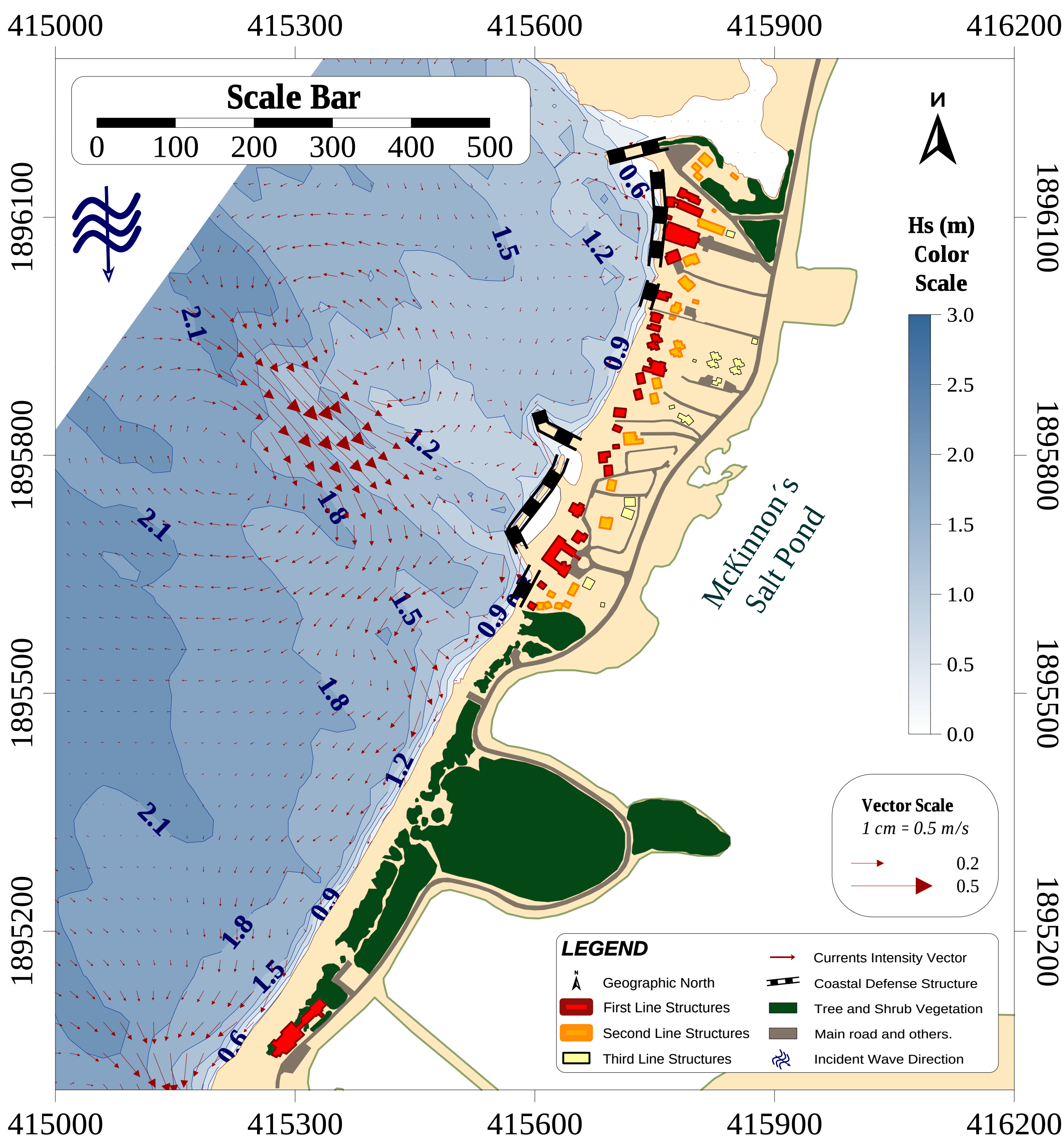
Graphic: Wave Height Color Scale + Vectors of Currents

TC RP 100 Years
Course: North
Hs = 8.51 m
Pp = 11.26 s

Software Developed by
MINISTERIO DE MEDIO AMBIENTE
GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 8.51 m* *h: 10 m* *fp: 0.09 Hz* *g: 5.0* *Nº Comp.: 10* ***Directional Spectrum*** *qm : -27.5° (N)* *s: 10° - Nº Comp.: 9*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

Graphic: Wave Height Color Scale + Vectors of Currents

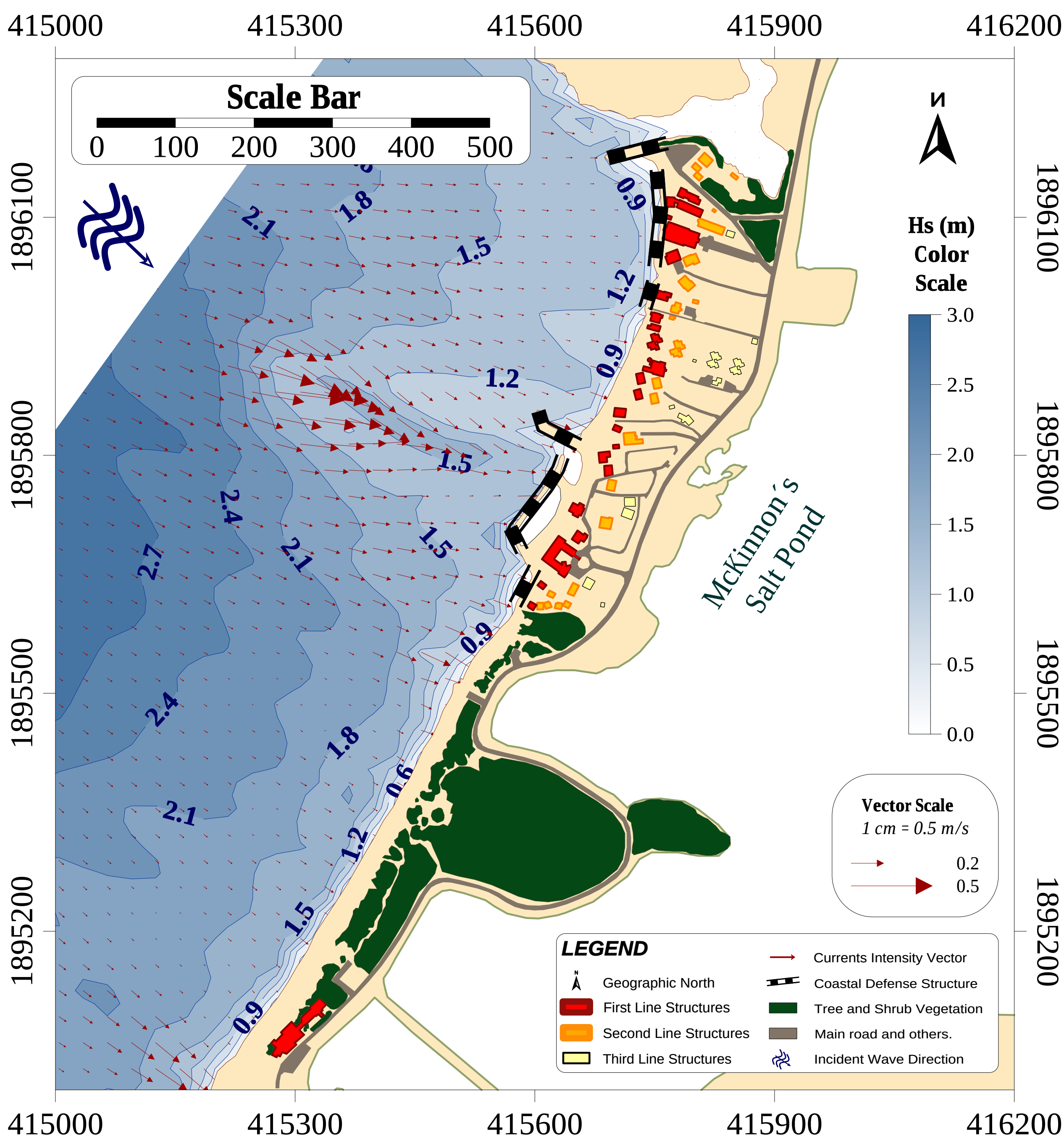
TC RP 10 Years
Course: NW
Hs = 5.71 m
Pp = 9.93 s

Software Developed by

MINISTERIO DE MEDIO AMBIENTE

GIOC

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 5.71 m* *h: 10 m* *fp: 0.11 Hz* *g: 3.3* *Nº Comp.: 12* ***Directional Spectrum*** *qm : -12° (N45.0W)* *s: 12° - Nº Comp.: 11*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

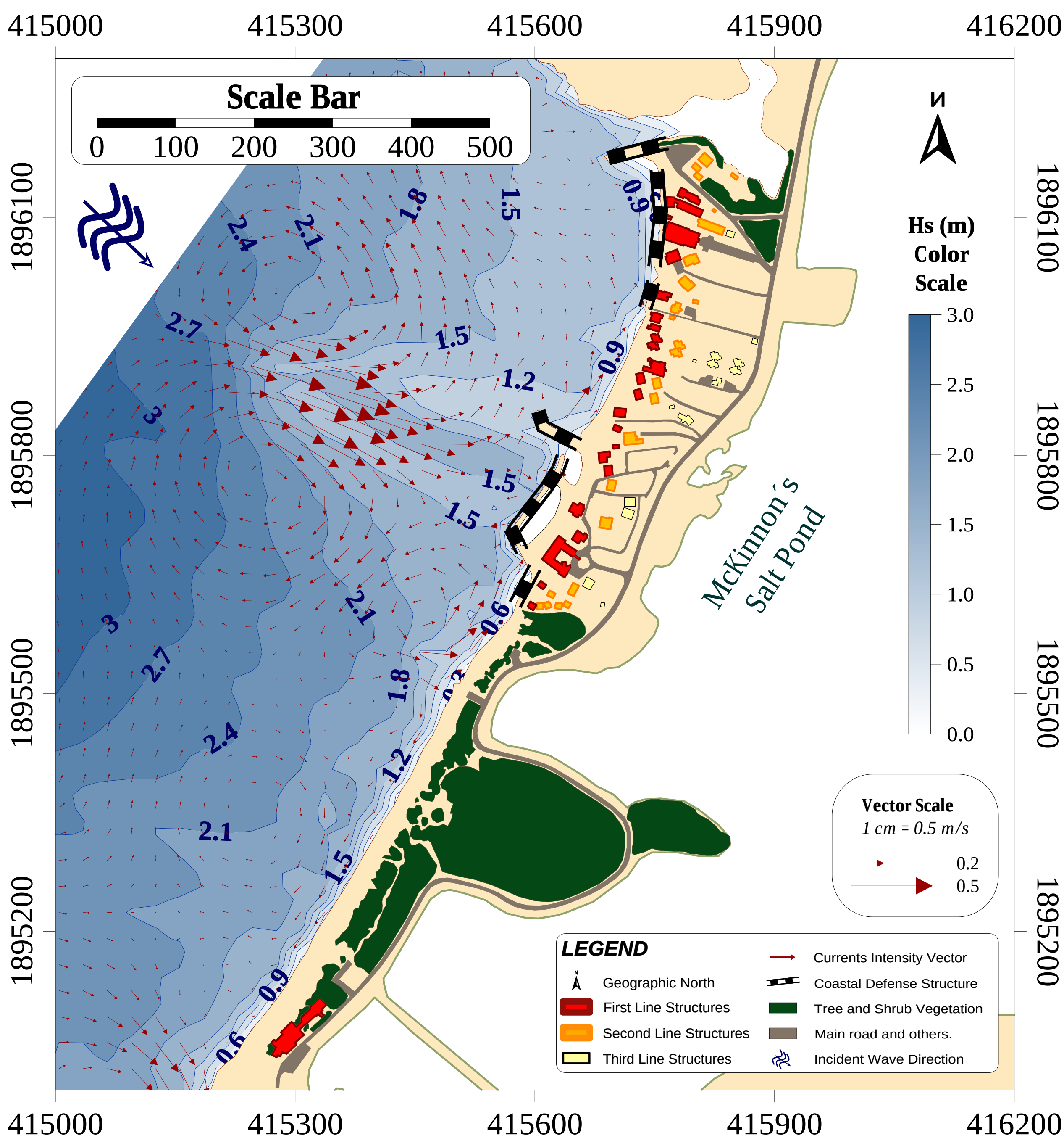
Project: Runaway Bay Beach. Antigua.

Graphic: Wave Height Color Scale + Vectors of Currents

TC RP 100 Years
Course: NW
Hs = 8.51 m
Pp = 11.26 s

Software Developed by
MINISTERIO DE MEDIO AMBIENTE
GIOC

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 8.51 m* *h: 10 m* *fp: 0.09 Hz* *g: 5.0* *Nº Comp.: 10* ***Directional Spectrum*** *qm : -10º (N45.0W)* *s: 10º - Nº Comp.: 9*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

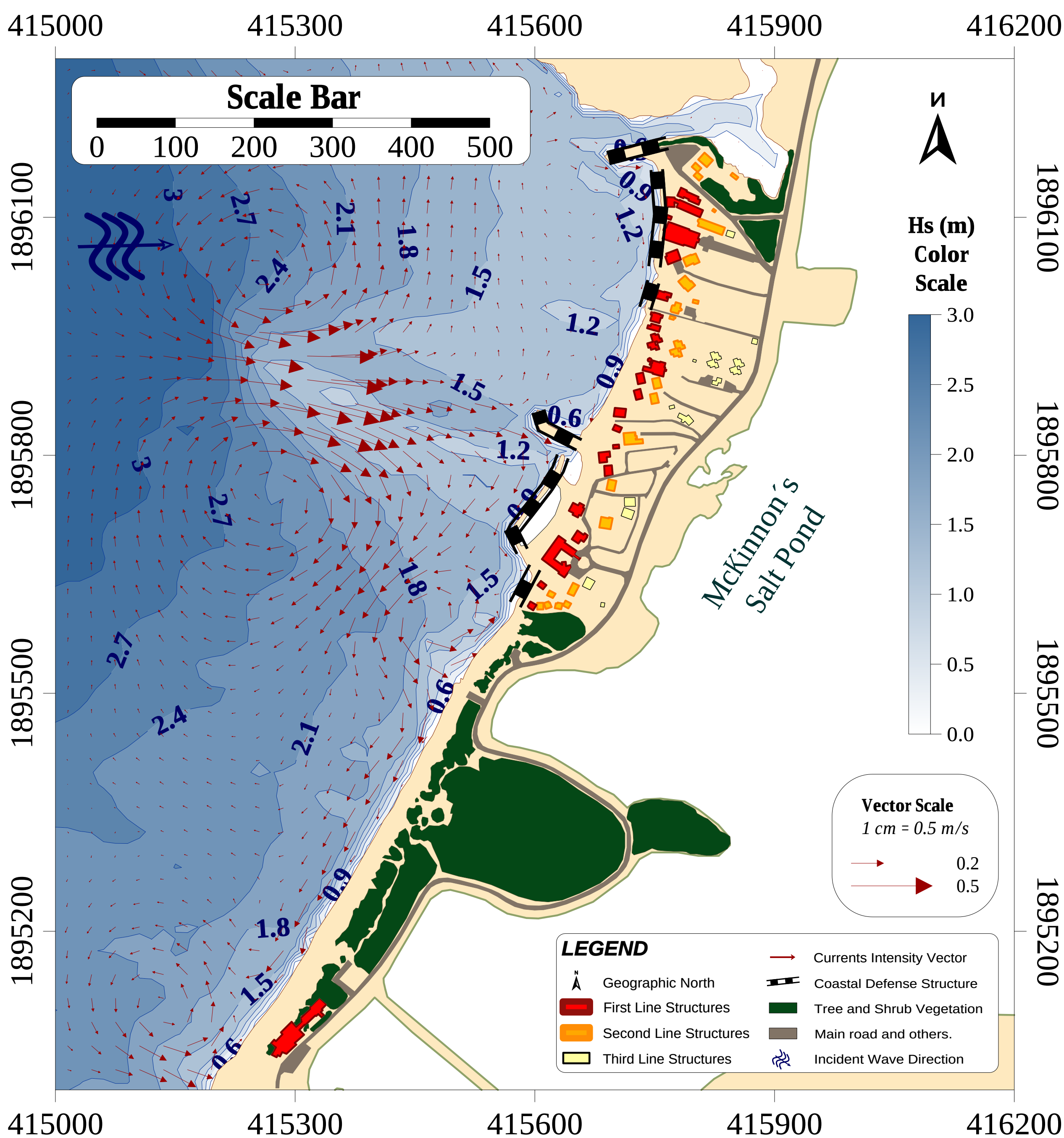
Graphic: Wave Height Color Scale + Vectors of Currents

TC RP 10 Years
Course: W
Hs = 8.57 m
Pp = 11.30 s

Software developed by MINISTERIO DE MEDIO AMBIENTE GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 8.57 m* *h: 10 m* *fp: 0.09 Hz* *g: 3.3* *Nº Comp.: 10* ***Directional Spectrum*** *qm : 0° (W)* *s: 10° - Nº Comp.: 9*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

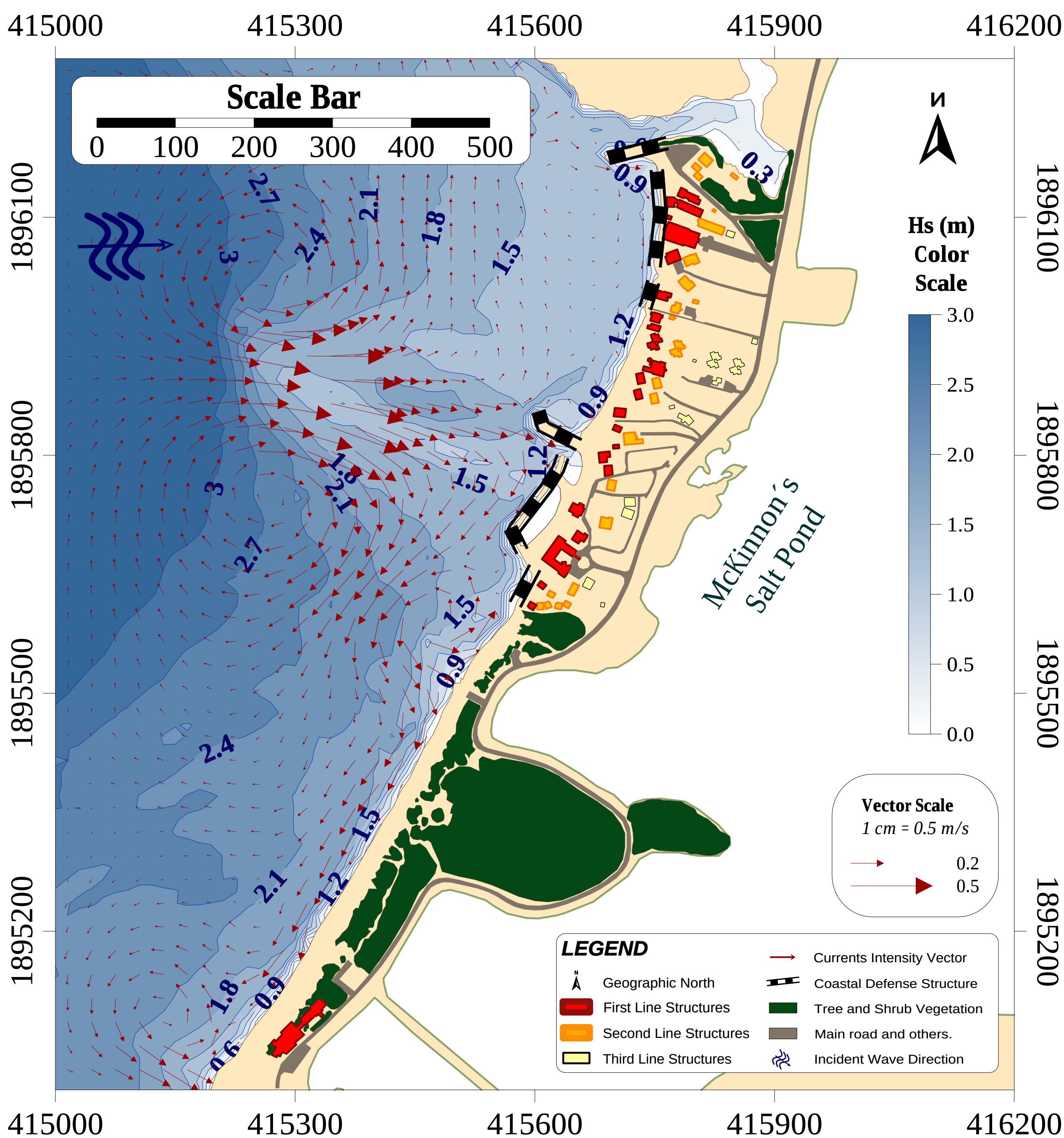
Project: Runaway Bay Beach. Antigua.

Graphic: Wave Height Color Scale + Vectors of Currents

TC RP 100 Years
Course: W
Hs = 12.76 m
Pp = 13.79 s

Software developed by

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 12.76 m* *h: 10 m* *fp: 0.07 Hz* *g: 5.0* *Nº Comp.: 8* ***Directional Spectrum*** *qm : 0° (W)* *s: 8° - Nº Comp.: 7*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

Graphic: Wave Height Color Scale + Vectors of Currents

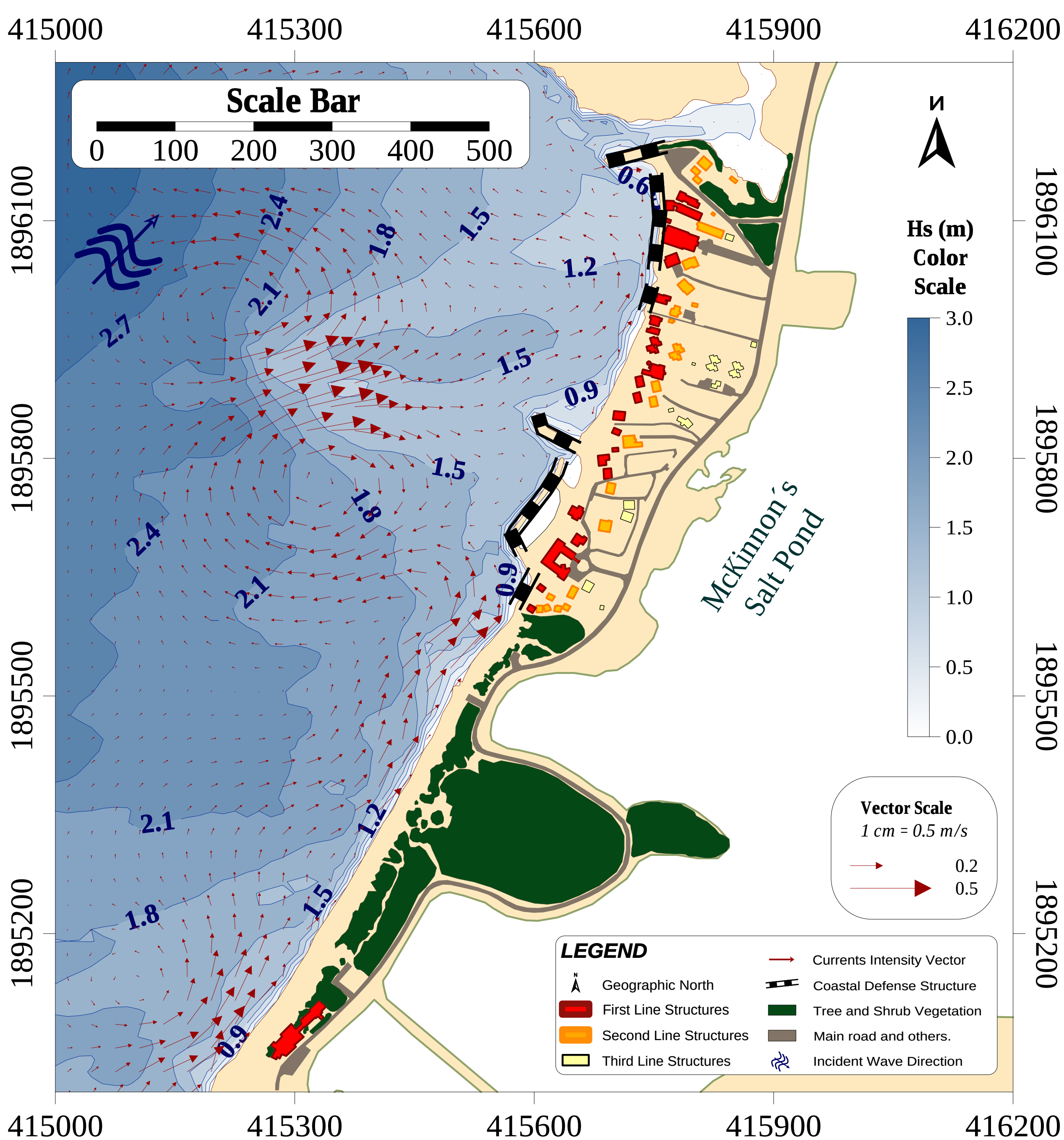
TC RP 10 Years
Course: SW
Hs = 8.57 m
Pp = 11.30 s

Software developed by

GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 8.57 m* *h: 10 m* *fp: 0.09 Hz* *g: 3.3* *Nº Comp.: 10* ***Directional Spectrum*** *qm : 45° (S45.0W)* *s: 10° - Nº Comp.: 9*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	



MOPLA 2.0: Inversiones GAMMA S.A.

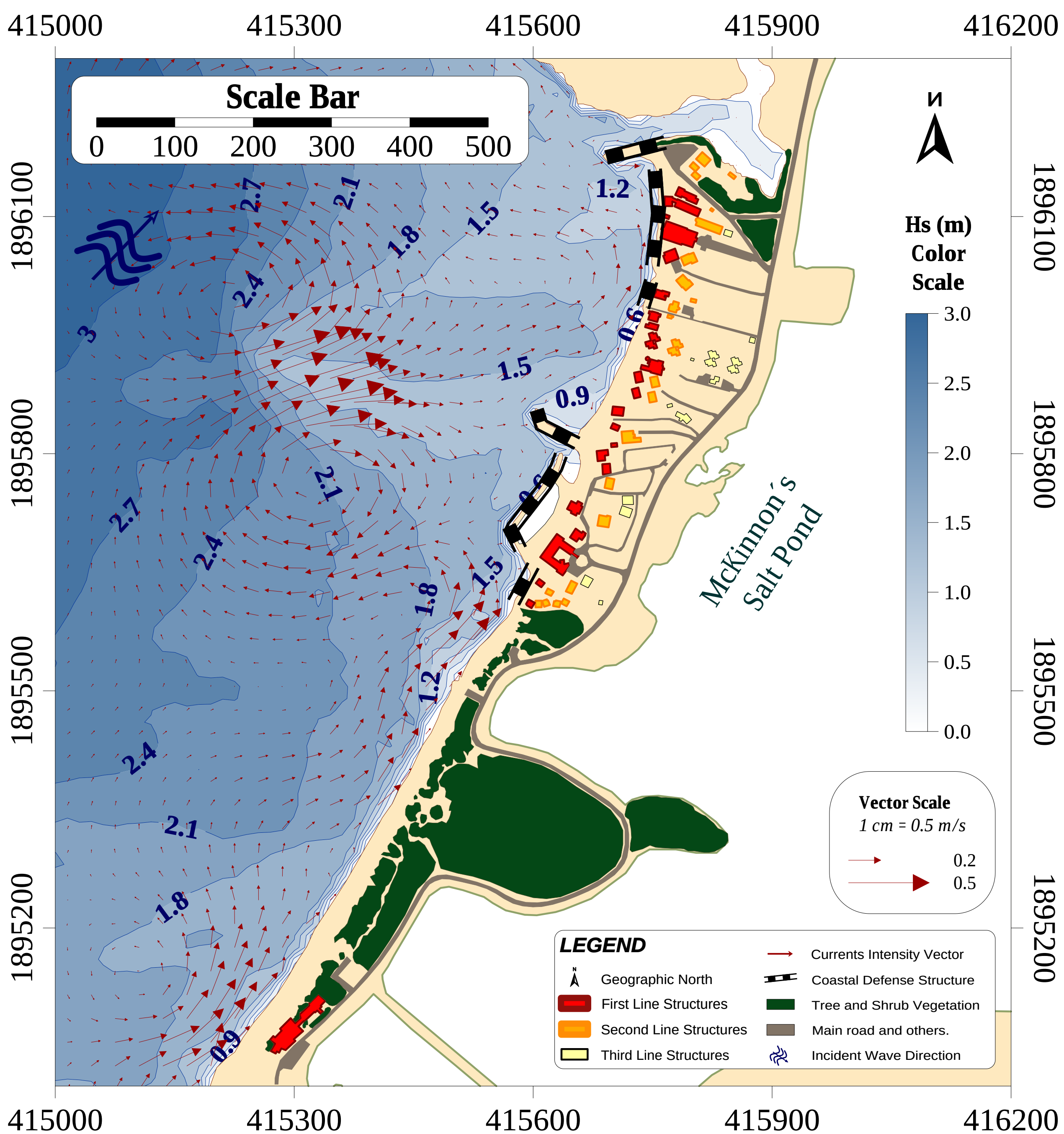
Project: Runaway Bay Beach. Antigua.

Graphic: Wave Height Color Scale + Vectors of Currents

TC RP 100 Years
Course: SW
Hs = 12.76 m
Pp = 13.79 s

Software developed by

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 12.76 m* *h: 10 m* *fp: 0.07 Hz* *γ: 5.0* *Nº Comp.: 8* ***Directional Spectrum*** *θ_m: 45° (S45.0W)* *σ: 8° - Nº Comp.: 7*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *ϵ: 8 m^2/s*	



ANEXO IV

Results of the Numeric Simulations

EROS-SP model

Coastal Sediment Transport and Seabed Variation

Project: Runaway Bay Beach. Antigua.

Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

Mean Regime
Course: NNE
Hs = 1.91 m
Pp = 8.78 s

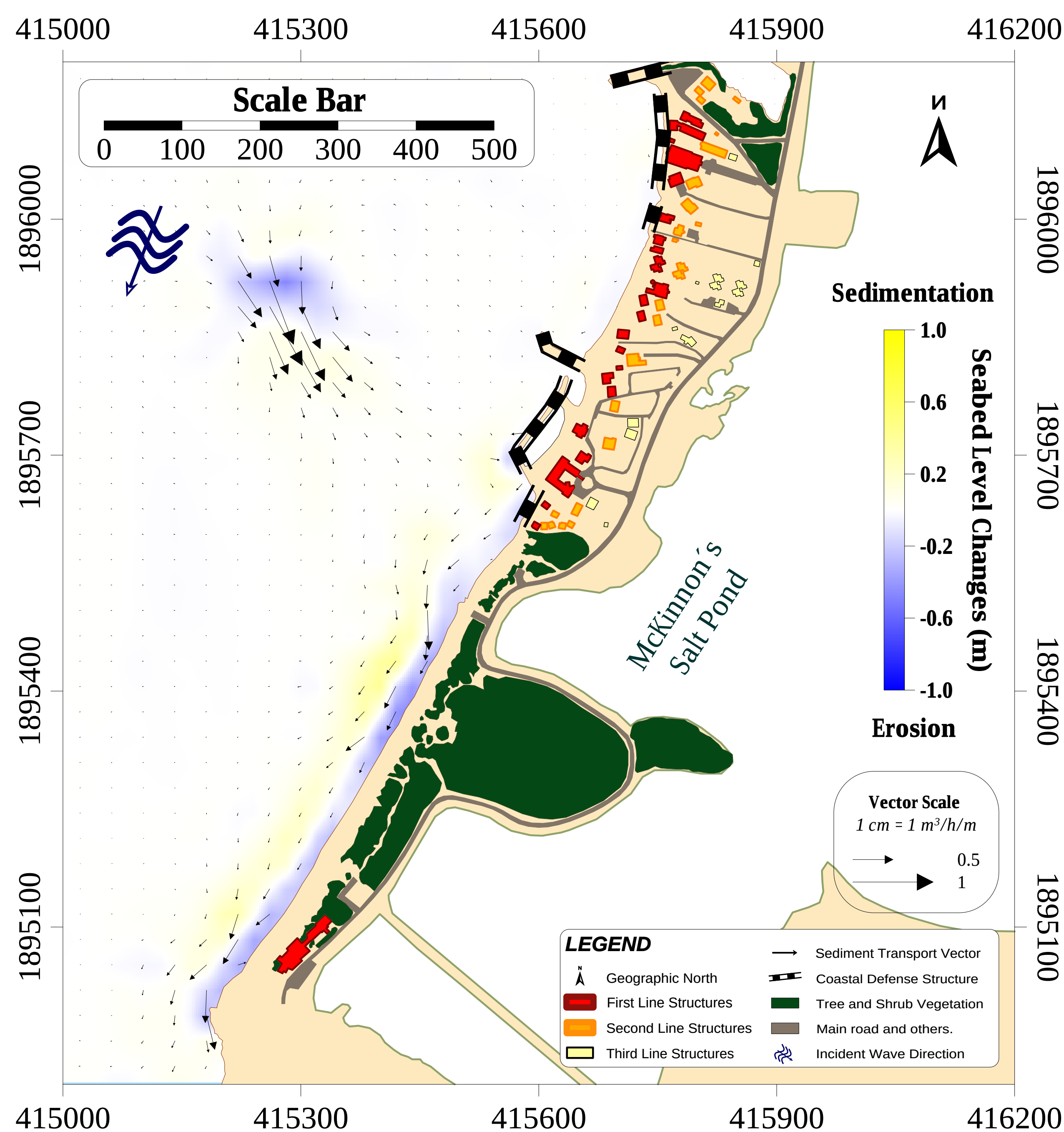
Software Developed by

MINISTERIO DE MEDIO AMBIENTE

GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 1.91 m* *h: 10 m* *fp: 0.11 Hz* *g: 3.3* *Nº Comp.: 16* ***Directional Spectrum*** *qm : -40° (N22.5E)* *s: 16° - Nº Comp.: 15*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 10 m^2/s*	*D_{50}: 0.25 mm* *Time: 12.0 h* *Formula: Soulsby*



MOPLA 2.0: Inversiones GAMMA S.A.

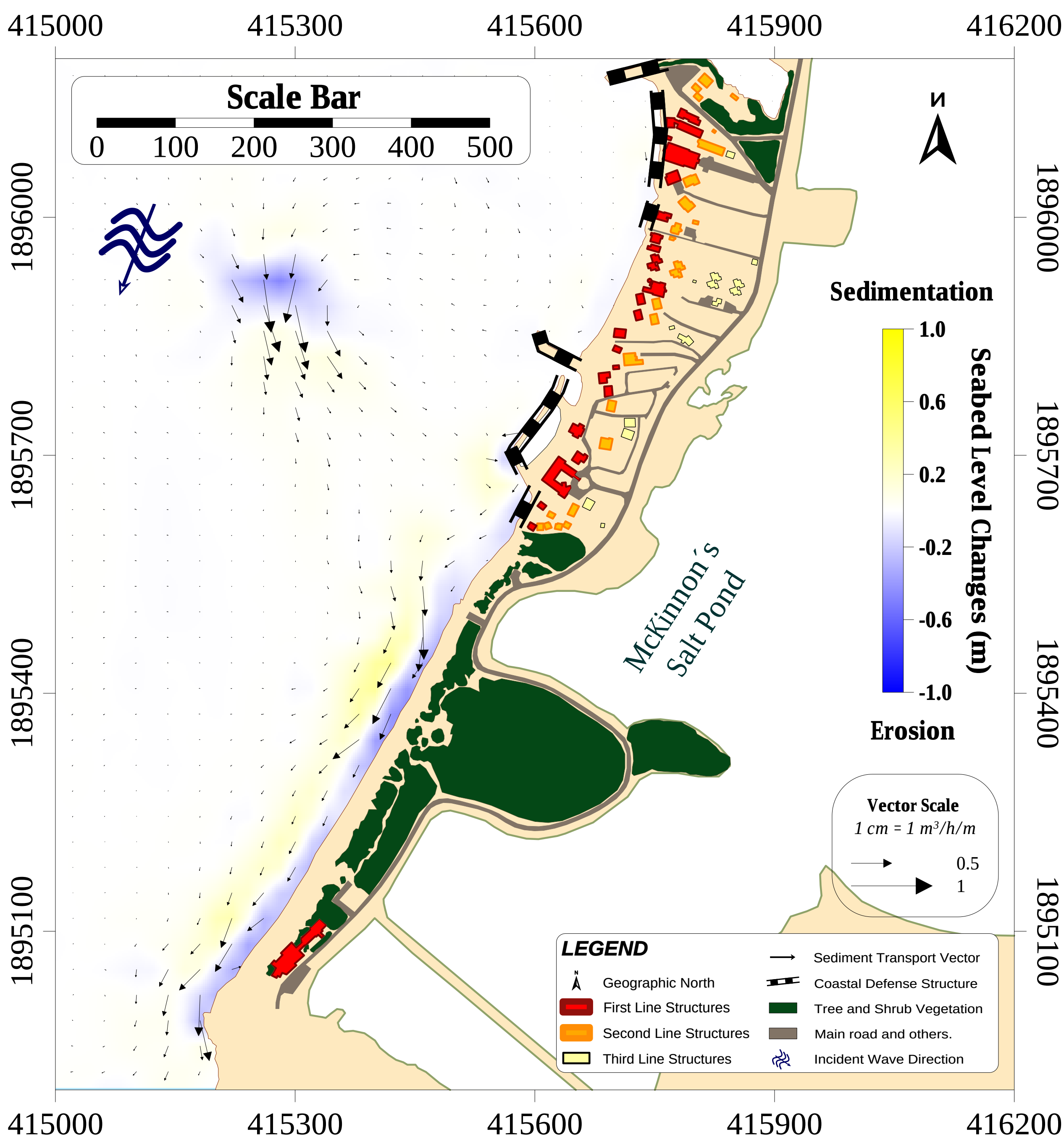
Project: Runaway Bay Beach. Antigua.

Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

Event of the Year
Course: NNE
Hs = 4.48 m
Pp = 8.78 s

Software Developed by

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 4.48 m* *h: 10 m* *fp: 0.11 Hz* *g: 3.3* *Nº Comp.: 12* ***Directional Spectrum*** *q_m: -40° (N22.5E)* *s: 12° - Nº Comp.: 11*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 10 m^2/s*	*D_{50}: 0.25 mm* *Time: 12.0 h* *Formula: Soulsby*



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

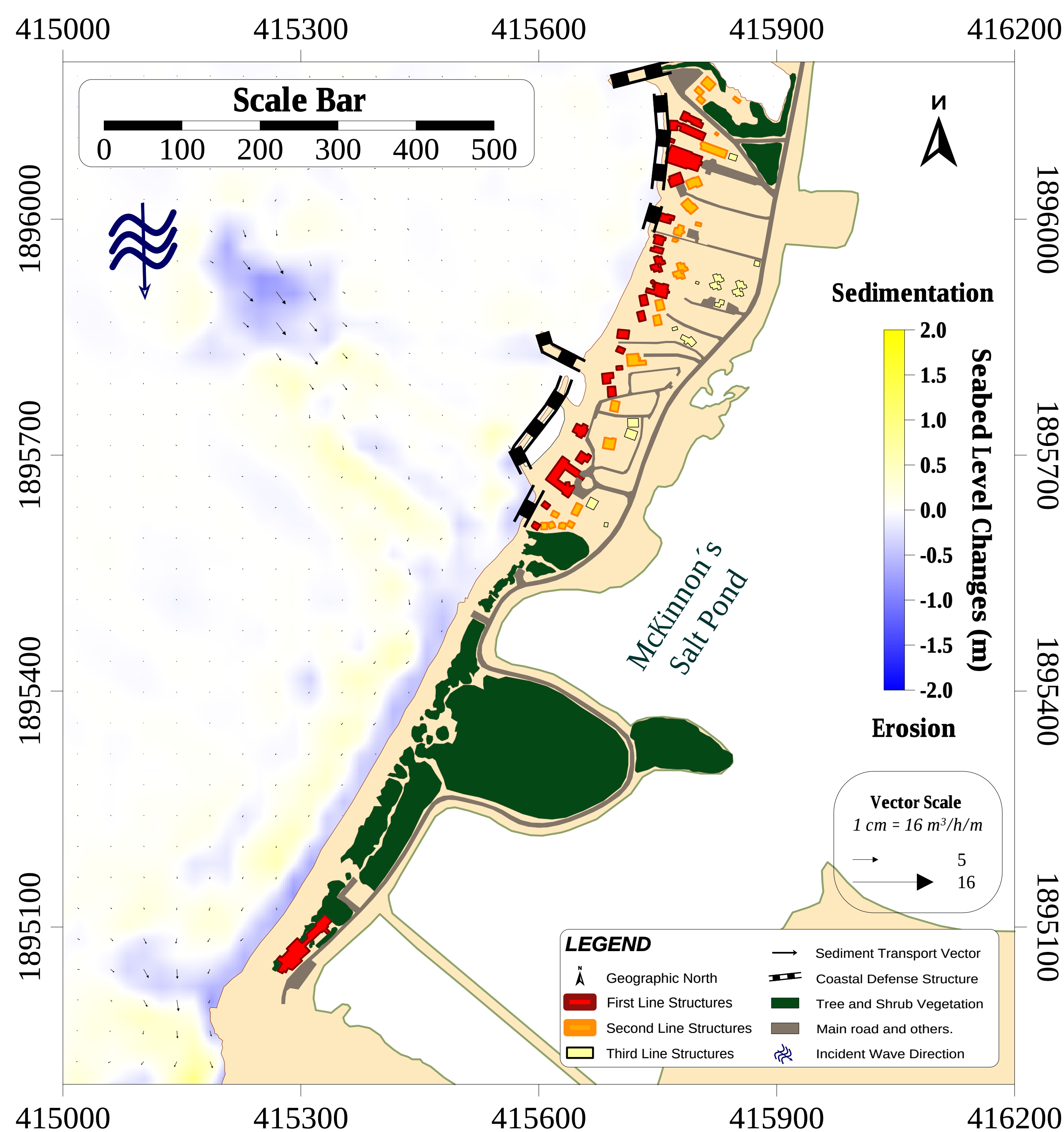
Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 10 Years
Course: North
Hs = 5.71 m
Pp = 9.93 s

Software Developed by MINISTERIO DE MEDIO AMBIENTE GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 5.71 m* *h: 10 m* *fp: 0.11 Hz* *g: 3.3* *Nº Comp.: 12* ***Directional Spectrum*** *q_m: -27.5° (N)* *s: 12° - Nº Comp.: 11*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 10 m^2/s*	*D_{50}: 0.25 mm* *Time: 12.0 h* *Formula: Soulsby*



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

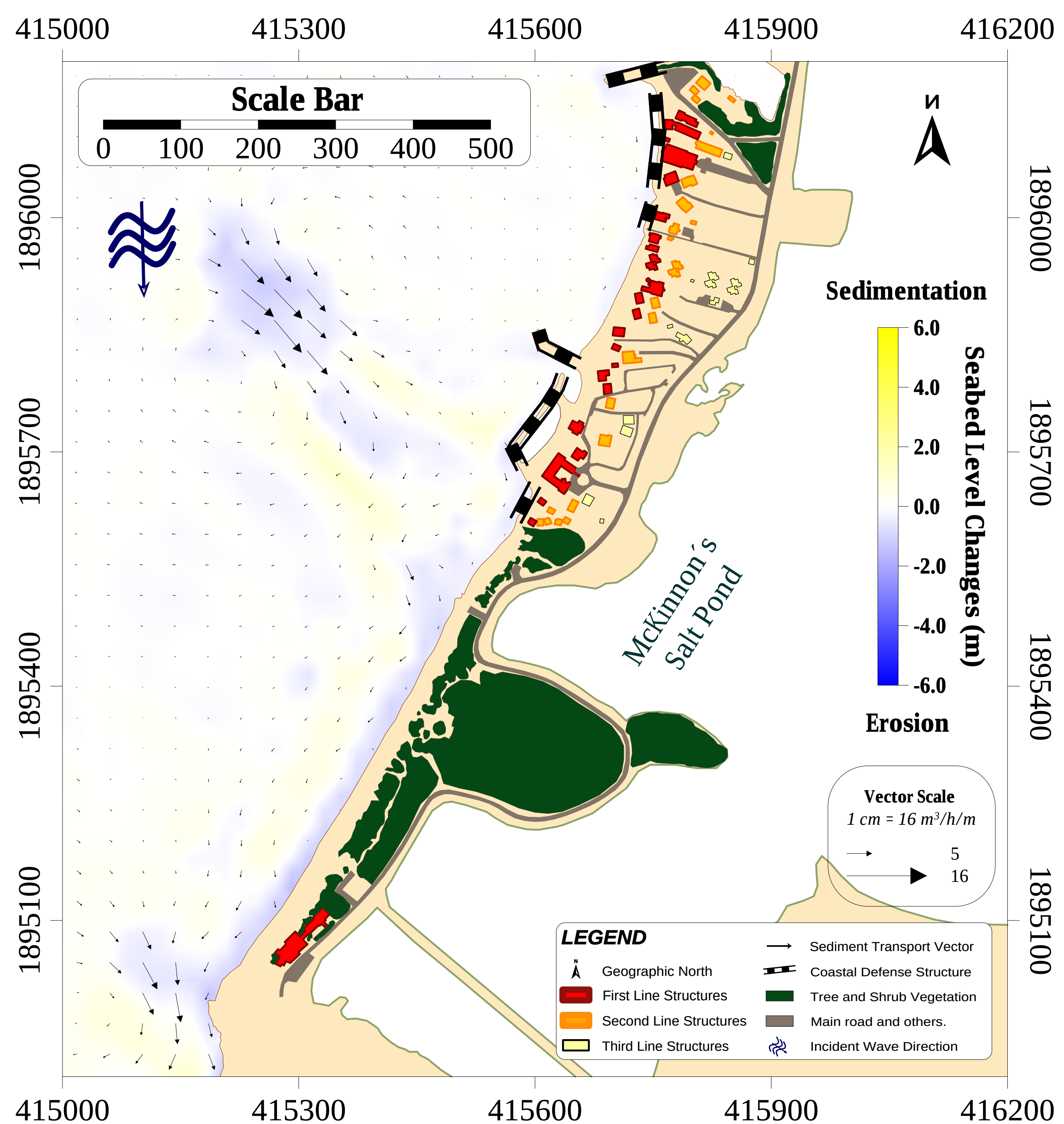
Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 100 Years
Course: North
Hs = 8.51 m
Pp = 11.26 s

Software Developed by
MINISTERIO DE MEDIO AMBIENTE
GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) Hs: 5.71 m h: 10 m fp: 0.11 Hz g: 3.3 Nº Comp.: 12 **Espectro direccional** qm : -27.5° (N) s: 12° - Nº Comp.: 11	Rugosity of Nikuradse Kswc: 1 m Swirl viscosity e: 8 m^2/s	D_{50}: 0.25 mm Time: 12.0 h Formula: Soulsby



MOPLA 2.0: Inversiones GAMMA S.A.

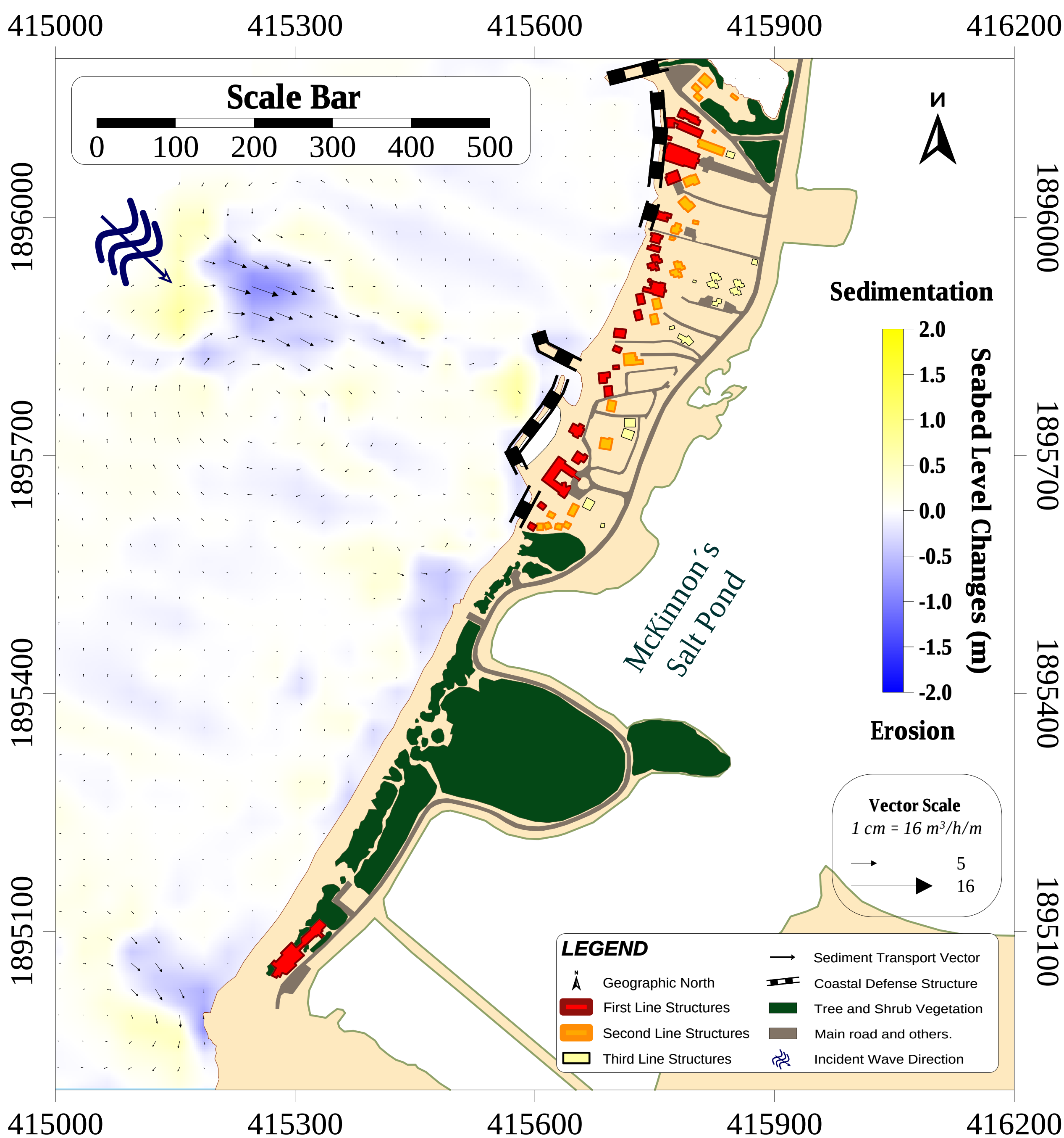
Project: Runaway Bay Beach. Antigua.

Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 10 Years
Course: NW
Hs = 5.71 m
Pp = 9.93 s

Software Developed by

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) Hs: 5.71 m h: 10 m fp: 0.11 Hz g: 3.3 Nº Comp.: 12 **Directional Spectrum** qm : -12° (N45.0W) s: 12° - Nº Comp.: 11	Rugosity of Nikuradse Kswc: 1 m Swirl viscosity e: 8 m^2/s	D_{50}: 0.25 mm Time: 12.0 h Formula: Soulsby



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

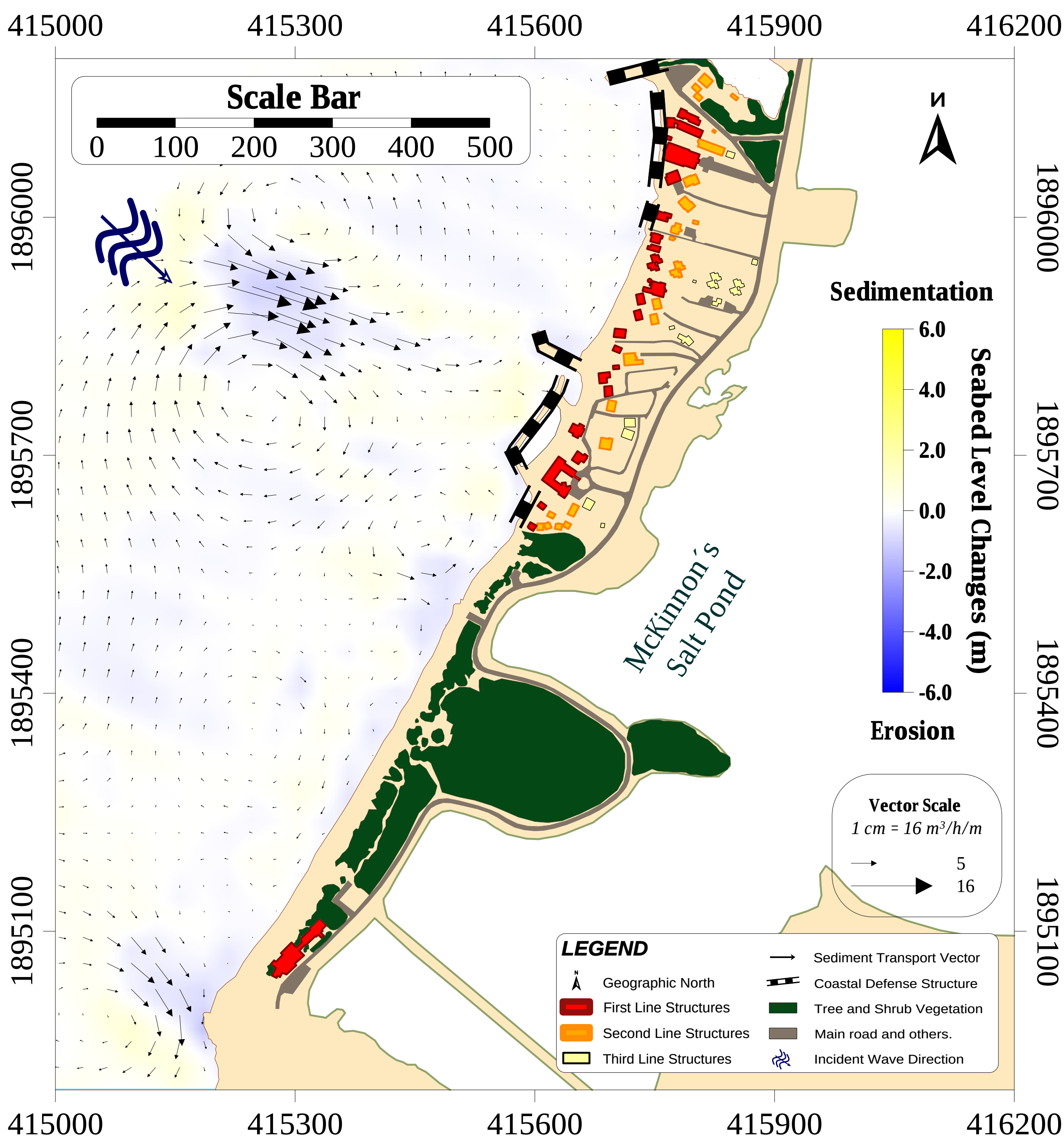
Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 100 Years
Course: NW
Hs = 8.51 m
Pp = 11.26 s

Software Developed by
MINISTERIO DE MEDIO AMBIENTE
GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 8.51 m* *h: 10 m* *fp: 0.09 Hz* *g: 5.0* *Nº Comp.: 10* ***Directional Spectrum*** *qm : -10° (N45.0W)* *s: 10° - Nº Comp.: 9*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	*D_{50}: 0.25 mm* *Time: 12.0 h* *Formula: Soulsby*



MOPLA 2.0: Inversiones GAMMA S.A.

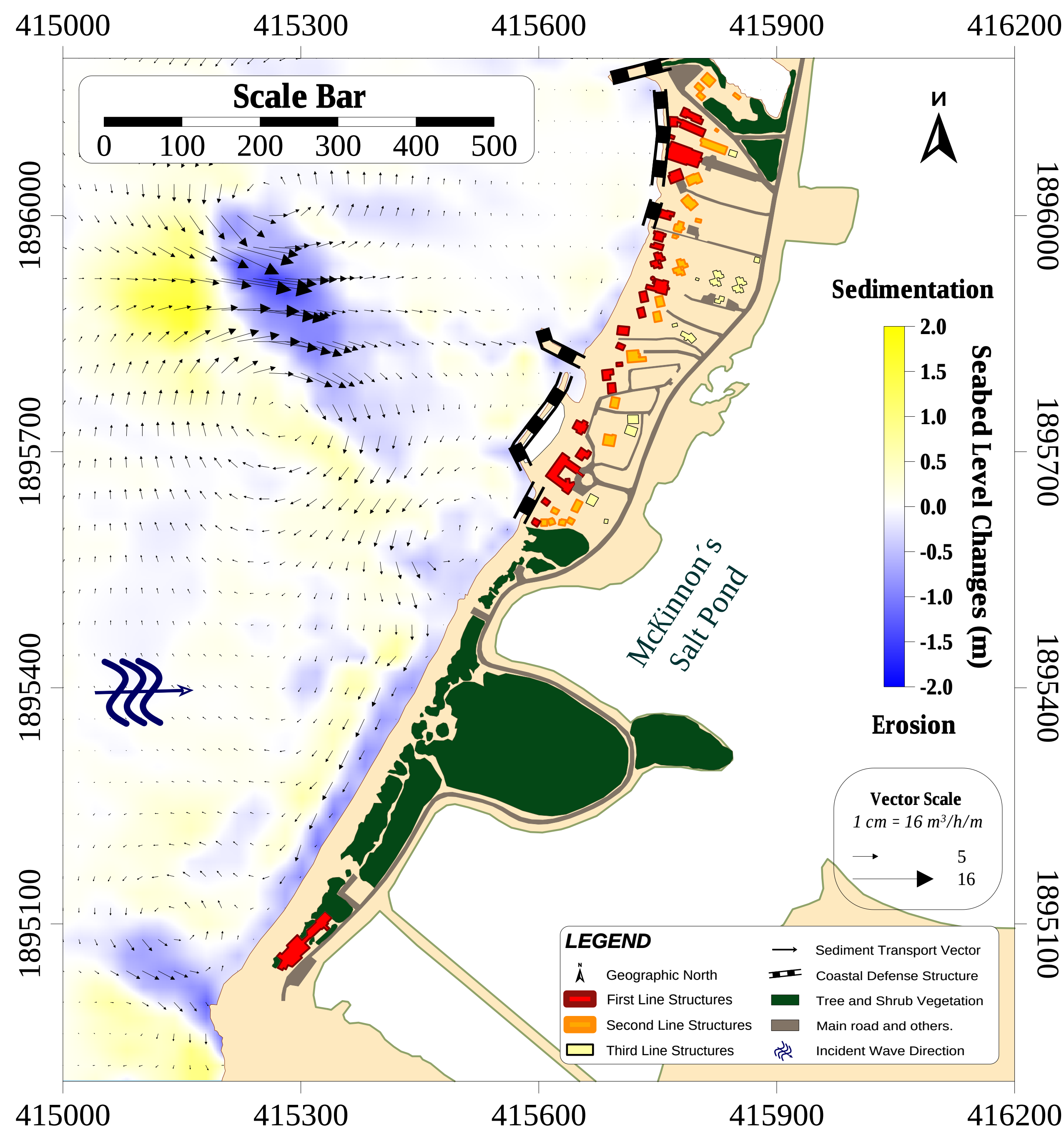
Project: Runaway Bay Beach. Antigua.

Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 10 Years
Course: West
Hs = 8.57 m
Pp = 11.30 s

Software Developed by GIOC

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) Hs: 8.57 m h: 10 m fp: 0.09 Hz g: 3.3 Nº Comp.: 10 **Directional Spectrum** qm : 0° (W) s: 10° - Nº Comp.: 9	Rugosity of Nikuradse Kswc: 1 m Swirl viscosity e: 8 m^2/s	D_{50}: 0.25 mm Time: 12.0 h Formula: Soulsby



MOPLA 2.0: Inversiones GAMMA S.A.

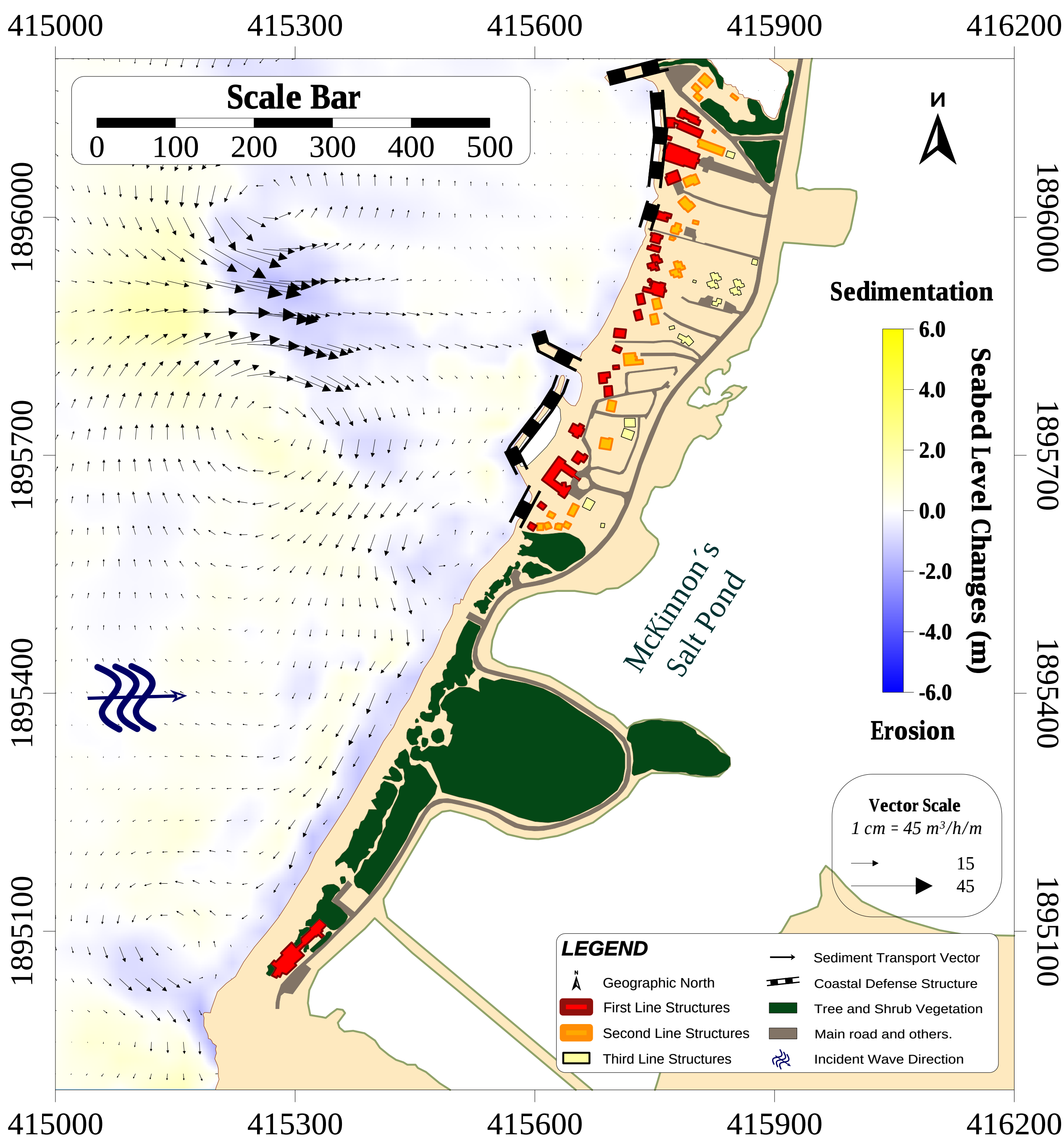
Project: Runaway Bay Beach. Antigua.

Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 100 Years
Course: West
Hs = 12.76 m
Pp = 13.79 s

Software Developed by

Simulation Characteristics		
OLUCA-SP	**COPLA-SP**	**MOPLA-SP**
Frecuencys Spectrum (TMA) *Hs: 12.76 m* *h: 10 m* *fp: 0.07 Hz* *g: 5.0* *Nº Comp.: 8* ***Directional Spectrum*** *qm : 0° (W)* *s: 8° - Nº Comp.: 7*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	*D_{50}: 0.25 mm* *Time: 12.0 h* *Formula: Soulsby*



MOPLA 2.0: Inversiones GAMMA S.A.

Project: Runaway Bay Beach. Antigua.

Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 10 Years
Course: SW
Hs = 8.57 m
Pp = 11.30 s

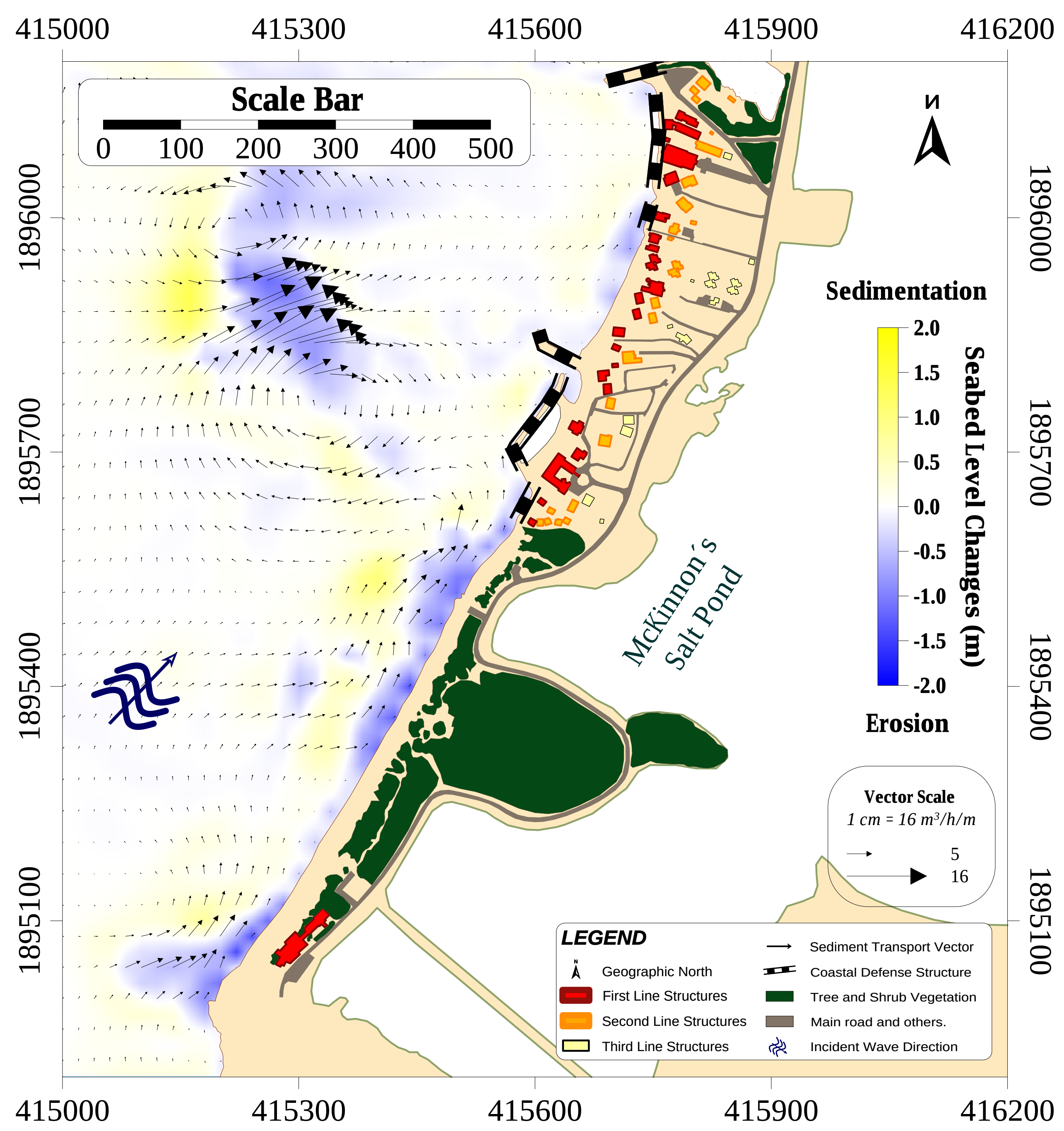
Software Developed by

MINISTERIO DE MEDIO AMBIENTE

GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 8.57 m* *h: 10 m* *fp: 0.09 Hz* *g: 3.3* *Nº Comp.: 10* ***Directional Spectrum*** *q_m : 45° (S45.0W)* *s: 10° - Nº Comp.: 9*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m^2/s*	*D_{50}: 0.25 mm* *Time: 12.0 h* *Formula: Soulsby*



Project: Runaway Bay Beach. Antigua.

Graphic: Seabed Changes Color Scale + Vectors of Sediment Transport

TC RP 100 Years
Course: SW
Hs = 12.76 m
Pp = 13.79 s

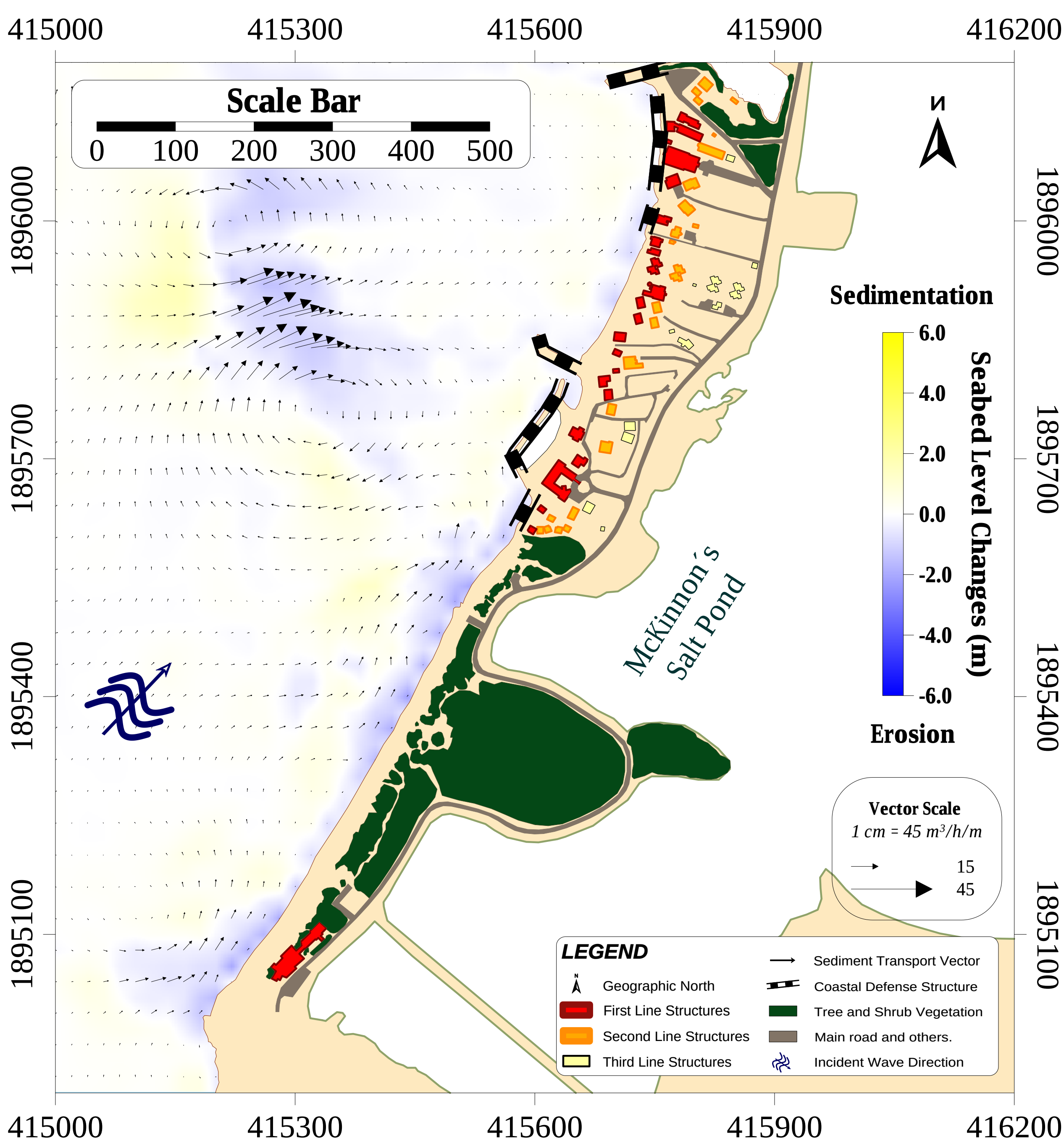
Software Developed by

MINISTERIO DE MEDIO AMBIENTE

GIOC

Simulation Characteristics

OLUCA-SP	COPLA-SP	MOPLA-SP
Frecuencys Spectrum (TMA) *Hs: 12.76 m* *h: 10 m* *fp: 0.07 Hz* *g: 5.0* *Nº Comp.: 8* ***Directional Spectrum*** *qm : 45° (S45.0W)* *s: 8° - Nº Comp.: 7*	*Rugosity of Nikuradse* *Kswc: 1 m* *Swirl viscosity* *e: 8 m²/s*	*D50: 0.25 mm* *Time: 12.0 h* *Formula: Soulsby*



MOPLA 2.0: Inversiones GAMMA S.A.